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CONTENTS

Page

Intestinal diseases of young calves with special reference to infection with *Bacterium coli*, REGINALD LOVELL 1

Incidence of calf diseases and mortality rates 2

Age incidence of colibacillosis and the natural immunity of calves 8

Aetiology of colibacillosis 10

The pathology of *Bact. coli* infection in calves 20

Epidemiology of white scours 21

Other intestinal diseases of calves 26

Acute gastro-enteritis of babies 27

Coccidial and other forms of parasitism in their relation to poultry husbandry, C. HORTON-SMITH 33

Systems of poultry husbandry 33

Development of Parasitism 33

Euthanasia, PHYLLIS G. CROFT 42

The appreciation of pain by animals 42

Methods of producing euthanasia 43

COMMONWEALTH BUREAU OF ANIMAL HEALTH

VETERINARY REVIEWS AND ANNOTATIONS

Vol. 1] April, 1955 [Part I

Intestinal Diseases of Young Calves with Special Reference to Infection with *Bacterium coli*

BY

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INTRODUCTION

The very young animal attempts to attain an equilibrium with its environment shortly after birth and this is not always accomplished without accident. The rapid transition from foetal life to that of a separate existence is dependent upon adaptation to a variety of circumstances. The new-born changes its method of respiration and is called upon to use its own lungs; its nutritional activities are altered and it has to modify its metabolism and eliminate its own waste products. It is called upon suddenly to adopt a relationship with other living agents in its immediate neighbourhood and failure to adapt itself may lead to death. Mechanisms are provided by nature to effect these changes and to overcome any of the hazards; many deaths and much illness may occur because these mechanisms are ignored or disregarded. Problems may therefore arise concerning circulation, respiration, temperature control and the risk of infection from living agents such as bacteria and viruses. Some bacteria are injurious to one species of animal and not to another; some may be especially injurious to animals of a particular age group. The biological and physiological condition of the host is thus as important as the nature of the parasite. Fixed ideas as to what is pathogenic are apt to lead one astray especially when considering diseases of the new-born. The outlook implies the multiplicity of causes in any one disease; subsidiary factors such as age, nutrition and immunity may be of equal importance. This, in turn, means a philosophical approach to the subject of parasitism which is a compromise between two living things; the general trend of that eternal struggle for food and shelter is towards a state of equilibrium. The ideal is a harmonious relationship between animals and the bacteria in their environment; the efficient parasite does not kill its host but lives in harmony with it. There are mechanisms provided whereby the new-born may resist bacterial invasion and adjust itself to this equable host-parasite relationship.

This relationship is unstable and is upset, frequently to the detriment of the host. Young calves, in particular, are prone to suffer from an intestinal disturbance known as "Scour", "Scours" or "White Scours". Many of the bacteria concerned are not pathogenic for adults, and calves meeting them for the first time succumb because of a faulty defence mechanism. This is really a failure at adaptation and serves to emphasize the importance of the subsidiary factors in infective diseases. Many of the bacteria involved are constantly present in the intestinal tract of adults and *Bacterium coli, Proteus vulgaris* and *Pseudomonas pyocyanea* are among those most frequently observed. The first mentioned is of the greatest frequency and in consequence the intestinal disorder with which it is associated may be referred to as "colibacillosis". Its separation from other intestinal disorders of calves is largely because of its age incidence, although intestinal and respiratory disturbances may go together as in some of those pneumonias of calves which have been described in recent years.

It is suggested that the most important cause of loss in calves is related to disturbances in the intestinal and respiratory tracts, and the evidence points to the domination of the intestinal disorders.

Summary. The concept of the equilibrium between host and parasite is introduced in order that the aetiology of intestinal disorders of the young may be appreciated. The failure of adaptation of the animal to its environment leads frequently to disease and death. Emphasis is given to the instability of this relationship between young stock and the bacteria in the immediate neighbourhood.

INCIDENCE OF CALF DISEASES AND MORTALITY RATES

The extent of the losses occasioned by disease and death in calves is calculated from special studies, from the experience of groups of farms, from the records of selected herds and from abattoir statistics.

At the end of last century the death rate in calves in Denmark was very high and Jensen (1893) gave some figures supplied by P. A. Mørkeberg, a state consultant. Of 211 calves born between October 1885 and June 1886, 122 died, a percentage of 57·8; from October 1886 to the 20th April 1887, 142 of 189 calves died, a percentage of 75·1. These calves were healthy at birth and died within about two days from a disease which was possibly white scours. At the beginning of this century a high death rate was experienced in some parts of Ireland; during a series of trials, the object of which was to prevent white scours, 69 of 213 calves died, a percentage of 32·4 (see Editorial 1903).

Thirty years later Jordan (1933) estimated the losses among a group of farms in Scotland; his survey included 26 farms in Ayrshire, and because of the early disposal of bull calves, he confined his attention to heifer calves. During 1931, 113 of 548 calves died and in the spring of 1932, 56 of 236 died; these are percentages of 20 and 24 respectively. At about the same time and in the same area Smith (1934)) collected the experiences from 52 farms; the percentage losses for the years 1931 to 1934 were 25 in the autumn, 8 in the spring with a mean of 20.

A more comprehensive investigation was necessary and this prompted the initiation of a survey of the deaths of calves in the dairy industry throughout Great Britain (Lovell & Hill 1940). A scheme of inquiry was drawn up with the assistance of the Central Council of Milk Recording Societies of England and Wales and records were collected from farms at intervals which were about 6 weeks. A total of 335 dairy herds scattered in different parts of England and Wales and 47 from a limited area in Scotland participated in the scheme and, as in other surveys, attention was paid to female calves because of the early disposal of bull calves. Of 12,544 calves born alive in England and Wales, 683 or 5·5 per cent died before the age of six months. Of 1383 born in Scotland, 158 or 11·4 per cent died before the age of six months. These observations were collected by official milk recorders at their periodical visits and gave an indication

of the problem and of the necessity for a detailed field survey. A detailed field survey of this nature had to be made by one individual who would correlate any mortality and disease with feeding, management and other environmental factors. This was made during the three-year period, 1946 to 1948 under the auspices of the Agricultural Research Council by Withers (1952-53) who recounted his observations on 44 herds in England and Wales and southern Scotland, which he visited at regular and frequent intervals; 35 were dairy herds and nine were beef and dual purpose herds. The over-all mortality of heifer calves in the dairy herds up to six months of age was 8·3 per cent, 310 of 3,744 calves having died. In England and Wales, 181 of 2,663 died, a percentage of 6·8 whilst in Scotland 129 died of 1,081 at risk, a percentage mortality of 11·9. The death rate in heifer calves was accepted as a true estimate because of the early disposal of bull calves; in the dual purpose herds the percentage mortality was 4·6, 32 calves of 697 at risk dying before the age of six months. At about this time, Hector and Rowat (1948) were making a survey in the Dumfriesshire area and they obtained data from 84 dairy herds. During 1946 and 1947, 61 of a total of 886 female calves died before reaching the age of 60 days, a percentage of 6·8.

A survey made in India by Minett (1946) yielded high figures. He confined his attention to female calves and during 1938-44, 159 of 599 born on a military farm at Secunderabad died giving a percentage mortality of 26·5. There was little difference in the figures given for the female offspring of buffaloes during 1939-44; 44 of 188 died, giving a percentage of 23·4. The figures for female calves at a military farm at Airfield (Lahore) were for 1939-44, 125 deaths out of 526, a percentage of 23·8.

These collected experiences show the difference in the mortality of calves over the years; it is extraordinary that losses of 57 and 75 per cent occurred 70 to 80 years ago and of over 30 per cent about 20 years later in Ireland. There is some evidence of improvement in the United Kingdom; losses reported in Scotland by Jordan and by Smith in the early part of the 1930's are much higher than those revealed in the figures of Lovell & Hill, Hector & Rowat and of Withers.

The information which accrues from farms or herds is influenced by the assumption that special care would be taken in herds in which complete records are kept. The mortality would probably be of a lower order and there should be additional data about the mortality in the different sexes.

There are several publications, concerning the happenings in herds in the U.S.A.—and the dates cover a number of years. From 1889 to 1928 the Cornell University Dairy herd contained descendants of a Holstein-Friesian cow born in 1887: from this original cow there were 191 female descendants in direct line and of 524 calves born to the 192 cows, 61 or 11·6 per cent died before reaching the age of three months (Wing 1933). The Iowa State College Dairy herd publish the recorded deaths of male and female calves and show a higher mortality among males than among females. During 1907 to 1936, 75 of 550 female calves born died before the age of six months and 154 of 606 male calves died. The greater number of deaths occurred during the first month of life and there is this sex differentiation: 13·6 per cent mortality in females compared with 25·1 per cent in males. There is little differentiation in the mortality among the sexes in the dairy herd of the Missouri Agricultural Experiment Station; the percentage mortality of 5·2 in females and 4·2 in males may be influenced by the differences in the breeds, which were Holstein, Jersey, Ayrshire and Shorthorn (Brody & Ragsdale 1936).

A brief picture of the differences according to the derivation of the data is shown in the accompanying table. The main value of the data is the definition of a problem and emphasis should be given to the loss which may occur even in herds which are permanently kept under expert care and supervision. There is some suggestion that the mortality is less to-day in Great Britain than it was some years ago and this may also be the case in other countries.

TABLE NO. 1

Mortality Rates in Calves

Date of observations and author.	*Nature of survey or herd.*	*Number of calves at risk.*	*Number died.*	*Percent-Mortality.*	*Sex, breed or other details.*
1885-1886 1886-1887 Jensen (1893)	Information received from a state consultant in Denmark.	211 189	122 142	57.8 75.1	Sexes not stated; deaths occurred in most cases in first two days.
1889-1928 Wing (1933)	Records of the Cornell University Dairy herd. (U.S.A.)	524	61	11.6	Offspring of 192 cows, Holstein-Friesians; from one cow in direct line. Deaths under 3 months; sexes not stated.
1903 Editorial (1903)	Abstract of results of trials for prevention of White Scours in Ireland.	213	69	32.4	Sexes not stated; deaths presumably from White Scours.
1907-1936 Ingels and Cannon (1936)	Records of Iowa State College Dairy herd. (U.S.A.)	550 606	75 154	13.6 25.1	F. M. All deaths under 6 months; greater number, especially in males were under one month.
From about 1906 to 1926 Brody and Ragsdale (1926)	Accumulated data over 20 years of dairy herd at Missouri Agricultural Experiment Station.	230 437 74 32	5 36 2 1		Holstein Jersey Ayrshire Shorthorn M. mortality 16/381. F. mortality 20/386.
1931 Spring 1932 Jordan (1933)	Data collected from 26 farms in Ayrshire (Scotland).	548 236	113 56	20.6 23.7	Heifer calves only; as bull calves are disposed of within 2-3 days. Deaths more frequent up to 7 days.
1931-1934 Smith (1934)	Data collected from 52 farms around Ayrshire (Scotland).	—	—	20	Heifer calves only. Deaths from few hours to a month.
1936-1937 Lovell & Hill (1940)	Inquiry of 335 herds in England & Wales and 47 in Scotland.	12,544 12,665 1,383 1,309	693 558 158 52	5.5 4.4 11.4 4.0	F. England & Wales M. England & Wales F. Scotland M. Scotland Attention should be confined to female owing to early disposal of male calves.

TABLE No. 1—Contd.

Date of observations and author	*Nature of survey or herd.*	*Number ofcalves at risk.*	*Number died.*	*Percent. Mortality.*	*Sex, breed or other details.*
1932-1942 Slack & Harrison (Savage & McCay 1942)	Cornell University Dairy herd (U.S.A.) continuation of data (see Wing 1933).	1,352 (conceptions) about 1,190 born alive.	144	12.1	Losses varied from 3-19 per cent annually. Sex not recorded.
1938-1944 1939-1944 1939-1944 Minett (1946)	Military Farm at Secunderabad. Military Farm at Airfield (Lahore) India.	599 188 526	159 44 125	26.5 23.4 23.8	F. from cows F. from buffaloes F. from cows Most deaths within first two months of life.
1946-1947 Hector and Rowat (1948)	Survey of farms in Ayrshire (Scotland).	886 739	61 15	6.8 2.0	F. M. Male mortality rate does not give true picture because of slaughter of young bull calves. Deaths were up to 60 days.
1946-1948	Inquiry of 44 herds in England & Wales and S. Scotland.	3,208	192	6	Includes 44 bought for rearing England & Wales. F.
Withers (1952-1953)		3,210	71	2.2	Includes 17 bought for rearing England & Wales. M.
		1,172 1,191	130 76	11.1 6.4	F. Scotland. M. Scotland. Many bull calves sold for slaughter and female figures give more reliable picture.

Some subsidiary data are revealed in the accounts given; the season of the year has some influence on the death rate of calves. Jordan (1933), Lovell & Hill (1940) and Withers (1952-53) all recounted the heavier losses in the early months of the year. Withers suggested that this is associated with the wide temperature variations and absence of sunshine which are common at this time. All observers agree that the highest mortality is in the very young calves and that the first week of life is the most hazardous. The personal factor was judged by Withers to be of prime importance in calf rearing and this in its turn influences the mortality; faulty methods of husbandry may be responsible, to a large degree, for the high incidence of disease and death in some herds. Climate and the personal factor exercise a direct effect and these play a part which is only equalled by the feeding or withholding of colostrum. Withers recorded that the aggregate death rates in the first month of life of heifer calves which received colostrum naturally, and by hand, were 3·9 per cent and 9·1 per cent, respectively. Lovell

and Hill also found that the death rates rose for both sexes in passing from the group of herds allowed colostrum naturally to those given it by bucket, and, finally to those from which it was withheld. There is thus statistical evidence supporting the contention that it is an advantage to allow the calf to take colostrum naturally from its mother. This is reflected in the recorded comparative death rates in calves from dairy herds and from beef and dual purpose herds. In Withers' experience there was a death rate of 5·2 per cent amongst bull calves and 3·8 per cent in heifer calves in the beef and dual purpose breeds of cattle; this difference in the sexes is similar to that in man. The average rate for heifer calves in dairy herds was 8·3 per cent and if the death rate in male calves could be determined in such herds it would probably exceed the female rate considerably. The lower rates in beef and dual purpose herds, compared with those in dairy herds, are clearly due to the more natural conditions of rearing which include suckling by the dams in yards or at grass.

Figures obtained from abattoirs may reveal a picture from another angle and in 1946 the authorities of eight large provincial abattoirs in Great Britain agreed to supply information concerning the incidence and reasons for the rejection of calf carcasses. Although the data dealt with rejection of carcasses as unfit for human food, it was expected that some information of value in relation to the problems of calf diseases might be acquired. All the abattoirs were situated in large provincial towns and the calves sent for slaughter were, for the most part, from commercial herds maintained solely for milk production. The calves were therefore a selected population and not representative and at the time of the inquiry calves of both sexes were sent to collecting centres as soon after birth as possible. The centres usually collected once a fortnight and calves of a day or so old were frequently sent as the owner had to balance the risk of condemnation of the carcass as immature against the cost of milk and labour for another 14 days. The ages of the calves may be estimated as from a few days to three weeks and the basic data are given in the following tables:—

TABLE NO. 2 A

Number and Percentage of Carcasses and Portions of Carcasses Condemned at Eight Provincial Abattoirs

Year and Quarter		*Number of calves Slaughtered*	*Number of carcasses or parts condemned*	*Percentage of condemnation.*
1946	2	37,513	784	2.1
	3	44,589	857	1.9
	4	62,609	1,186	1.9
1947	1	49,297	1,482	3.0
	2	28,649	1,248	2.5
	3	39,704	1,099	2.8
	4	48,536	1,370	2.8
1948	1	37,194	904	2.4
	2	17,843	381	2.1
	3	33,020	526	1.6
	4	47,414	766	1.6
1949	1	33,036	806	2.4
Totals		479,404	11,409	2.4

An analysis of the reasons given for the rejection of the carcasses or parts thereof is shown in Table 2B below:—

TABLE No. 2 B

Number and Percentages of Carcasses and Portions of Carcasses Condemned Classified According to Recorded Reasons for Condemnation

Reason for condemnation	*Numbers condemned*		*Percentages of total condemned*	
Immaturity		5,840		51.2
Moribund	768		6.7	
Emaciation	826		7.2	
Congestion	377		3.3	
Injuries, etc.	169	2,140	1.5	18.7
General conditions including navel-ill, scours, cellulitis, etc.	729		6.4	
Conditions of special organs, *e.g.* pleurisy, nephritis, hepatitis, etc.	653		5.7	
Pyaemia	191		1.7	
Parasitic diseases*	153		1.3	
Pneumonia	308		2.6	
Abscess formation	233		2.0	
Melanosis	87		0.8	
Tuberculosis	1,075	3,429	9.4	30.1
		11,409	—	100.0

* This term is employed in the sense in which it is used in abattoir returns

The conditions are recorded in the terms used in meat inspection, and "immaturity", which accounts for over half of the rejections, is based on the appearance of the flesh; loose flabby flesh and a lack of muscular development are the general indications. It is a matter of conjecture as to how many of the calves would have produced suitable meat if they had been allowed to live longer; it is highly probable that many of those condemned were sent to collecting centres because the owner wished to save labour and milk. Those conditions which are included in "moribund, emaciation, congestion and various injuries" amount to a further 2,140 and are 18·7 per cent of the total condemned. In some respects these are allied to "immaturity" in that the calves were unfit for slaughter and it is therefore permissible to add these to the immaturity group, making a total of 7,980; these calves should not have been slaughtered and they account for 70 per cent of the rejections made at *post-mortem* examinations.

The remainder of the conditions cited include "general conditions" and "conditions of special organs". Within these categories there are cases of pyrexia, navel-ill, scours, pleurisy, peritonitis, pericarditis, hepatitis, enteritis, calf diphtheria, joint-ill and arthritis. Tuberculosis accounts for 9·4 per cent of those condemned and 0·2 per cent of the total number slaughtered. Pneumonia and abscess formation are 2·6 and 2·0 per cent respectively. It would therefore be fair to say that, with the exception of melanosis and the parasitic diseases, most of the conditions included in this group are infective diseases and account for 3,189 rejections or approximately 28 per cent. This low percentage of rejections due to established causes accounts for less than 0·7 per cent of the total slaughtered and if this is compared with the mortality in dairy herds, it indicates that the bulk of the diseases in young calves are concerned with conditions encountered in their post-natal environment; they are not engendered whilst in the uterus of the mother.

This accords well with the experience of Pullinger (1950) who surveyed the reasons for the condemnation of calf carcasses at Johannesburg abattoir during the years 1945-49. The percentage of rejections varied from 0·782 to 1·820 and a high proportion of them was for avoidable causes. His figures indicate that emaciation, immaturity and bruising may account for upwards of 76 per cent of the condemnations, the remainder being due to jaundice, pyaemia, pneumonia, pleurisy and enteritis.

Summary. The losses in calves have been calculated from special studies, from the experiences of groups of farms, from the records of selected herds and from abattoir statistics. Seventy years ago there were death rates of 60 and 70 per cent and at the turn of the century losses of over 30 per cent were experienced. Within recent years death rates of 6 to 11 per cent have been recorded for female calves in dairy herds; the actual death rates in bull calves are difficult to assess. There appears to be a lower death rate in beef and dual purpose herds. The most hazardous time for the calf is its first week and possibly first month of life.

In general there are heavier losses amongst spring calves and this may be associated with the wide temperature variation common at this time. Faulty methods of husbandry, lack of, or delay in obtaining colostrum and a personal factor contribute to the causes of these deaths.

It has been estimated that about 2·4 per cent of calves slaughtered are condemned because of unsuitability for human consumption. The most common reason for condemnation was immaturity; this may have been associated with the economic conditions prevailing in the immediate post-war period. The low frequency of rejections on the grounds of established diseases when compared with the mortality of calves in dairy herds, suggests that most of the diseases in young calves are concerned with their post-natal environment.

AGE INCIDENCE OF COLIBACILLOSIS AND THE NATURAL IMMUNITY OF CALVES.

Colibacillosis or White Scours is essentially a disease of the very young calf and according to Jensen it had been known for 100 years when he described the disease in 1893. Calves, which were healthy at birth, died within one or two days from a septicaemia with inflammation of the intestines. Mettam (1903) recorded the frequency of diarrhoea in calves in Ireland on the second and third day of life; respiratory disturbances occurred some weeks later. American experience accords with these observations and Smith and Little (1922) wrote of the deaths in calves in the first week of life; of eight calves dying in their recorded experiment seven were less than 7 days of age. Of the 100 calves examined bacteriologically

by Lovell and Hughes (1935) 25 were less than 7 days old and 28 were from 7 to 14 days of age. It is possible that there were more in the latter age-group because of the inclusion of calves bought for a nutritional experiment. On the other hand, 37 of the 100 calves examined had died from colibacillosis, 22 by the seventh day and another 11 by the 14th day. Nearly half of the deaths in female calves recorded by Lovell and Hill (1940) took place in the first week of life and 61 per cent within the first two weeks. Withers (1952–53) recorded similar observations, 48 per cent of deaths in the first week and 66 per cent in the first fortnight. Furthermore, of the total of 469 deaths recorded, 131 were stated to be due to *Bact. coli* infection and 85 of these occurred during the first week with a further 22 in the second week.

The age incidence and the frequency of this disease account for these authors (Lovell and Hill 1940, Withers 1952–53) giving the opinion that the important hazard in the first week or fortnight of the calf's life is white scours or colibacillosis, and that the commonest single cause of deaths appears to be *Bact. coli* infection.

From early times the importance of colostrum in the nutrition of calves has been appreciated and Smith and Little (1922) drew attention to the association between white scours and the lack of colostrum. All of 10 calves permitted to take colostrum after birth survived, whereas 8 of the 12 which did not get it died and one was killed when moribund. Many years before, Ehrlich (1892) immunized mice against toxic proteins and showed the transference of some immunity through the mammary secretions. Famulener (1912) found that the colostrum of goats immunized against sheep corpuscles was much richer in antibodies than the serum. It is well recognized that the young derive from the mother any immunity they enjoy either before birth or shortly afterwards. The relative importance of the mode of transfer varies from species to species and whilst cattle, sheep, goats, horses and pigs appear to obtain their immunity from the ingestion of colostrum, human beings, rabbits and guinea pigs acquire theirs whilst still within the uterus.

The actual absorption in the new-born calf is almost entirely by the small intestine and the route taken by the globulins from the small intestine is almost exclusively by way of the lymphatics. Comline *et al.* (1951) introduced colostral whey into the duodenum and found that absorption occurred 6–27 hours after birth but not 63–64 hours after birth. The immune lacto-globulins differ in their electrophoretic mobility from immune serum globulins and those identified in calf serum after the ingestion of colostrum behave as lacto-globulins. There is therefore direct evidence of this absorption of antibodies from colostrum.

The association between the transference of antibodies and colibacillosis in calves was emphasized by Smith and Little (1922) who pointed out that the calf deprived of colostrum lacked something which prevented intestinal bacteria from invading the body and multiplying in various tissues. In most cases the disease developed into a septicaemia and special races of *Bact. coli* were frequently responsible; the most invasive of the microflora of any herd would tend to dominate the bacteriology. There thus exists in the young calf, a delicate balance between certain strains of *Bact. coli* and the tissues; if this balance is upset in favour of the bacteria scours will result. Special types of *Bact. coli*, insufficient or inadequate colostrum, or delay in feeding which may lead to hurried ingestion and distension in the intestinal tract, may disturb this balance. According to Smith and Orcutt (1925) the immediate reactions are, a great increase in the number of *Bact. coli* in the lower part of the small intestine with an upward spread, and a general intoxication. Inadequate digestive functions are as important as the increasing virulence of the strain of *Bact. coli*. Some few years later Smith (1930) recorded the presence of antibodies against scour-strains of *Bact. coli* in the colostrum of normal cows. The protective capacity of some samples was low and these had been obtained from cows whose entry into the herd was shortly before calving;

the inference being that they had not been immunized to the new microflora. Further observations confirmed that the milk following the colostrum loses its protective power and that the serum of normal cows drawn at the same time as the colostrum is distinctly below the colostrum in antibody content. The linkage between the colostrum, its adequacy and significance to the new-born calf on the one hand, and the environmental bacteria, especially *Bact. coli*, on the other, has been well established. The ability of the new-born calf to avail itself of the protection at hand has also been accepted; the absorption of the globulins of the colostrum by the new-born animal is a physiological function and is independent of the presence or absence of antibodies (Orcutt and Howe 1922). It is possible therefore that colostrum is of benefit to the calf in many ways and this accounts for the differences of opinion as to how colostrum exerts its action. It undoubtedly confers a passive immunity and it may benefit the calf because of its vitamin content or because it supplies the new-born with protein. There is little doubt, however, that the occurrence of colibacillosis is indicative of a failure in utilizing this mechanism or signifies a disturbance of its efficiency.

Summary. Colibacillosis is essentially a disease of very young calves and is the greatest hazard in their first week or fortnight of life. The importance of colostrum in the nutrition of calves has been appreciated and this is clearly associated with the transference of the globulins from mother to offspring. The route of this transfer varies in different species of animal, and in cattle these maternal globulins, which may or may not be associated with antibodies, are conveyed in the colostrum. The natural immunity of the calf to prevalent bacteria is therefore dependent upon its supply of colostrum. Lack of colostrum enables bacteria to multiply in the intestinal tract of the calf, and to invade the different tissues. The association between the colostrum of a cow and the bacteria in her environment during pregnancy is therefore of some significance to the calf.

AETIOLOGY OF COLIBACILLOSIS

It has been emphasized many times that aetiology in the medical sense is the science of the causes of disease and that a multiplicity of factors is involved. A specific parasite may have little effect unless it is influenced by subsidiary conditions. The importance of age has already been stressed as well as the nutritional status and general management of the animal. The density of the animal population, climate and geographical and geological factors add their contributions. Ryle (1948) has pleaded for a concept of social medicine and social pathology, which is the medicine and pathology of families, groups, societies and large populations. Such an outlook should lead to a fuller understanding of the circumstances which lead to the development of morbid changes; it is true that Ryle was dealing with diseases and hazards associated with human welfare, but similar investigational methods could be used profitably in animal diseases. Lovell and Hill (1940) and Withers (1952-53) stressed these subsidiary factors which seem to be implicated in calf mortality in Great Britain; the seasonal swing, the increase in the death rate as one passes northward and the slightly higher death rate in small herds may all play some part in aetiological studies. Added to these are the observations concerning the apparent deleterious effect of wide temperature variations and lack of sunshine.

There is also the realization that the ability of a given strain of micro-organism to produce a pathological state in a given host does not imply necessarily that the bacterium has some intrinsic property, but that there is a particular host-parasite relationship which, in this case, is detrimental to the host (Dubos 1945). This is especially so in infections of young stock because many bacteria which are non-pathogenic for adults may cause disease and death in the new-born. Spence (1941) summarized this by stating that "an organism such as *Bact. coli* which is relatively innocuous to older children may cause a rapidly fatal illness in a

new-born infant and an investigating bacteriologist with fixed ideas of what are pathogenic organisms may be led astray".

This outlook is not new nor modern and veterinary pathologists recognized from early days that calves could be killed by *Bact. coli*.

The Specific Organism. The significance of *Bact. coli* in the aetiology of white scours was recorded in Denmark by Jensen (1893, 1911), by Nocard and Leclainche (1898) in France and by Joest (1903) and by Titze & Weichel (1908) in Germany. Confirmation and further observations were made in America by Smith and Little (1922, 1927) and by Smith and Orcutt (1925) and other workers. The first recorded observations made in Great Britain were those of Lovell & Hughes (1935) and Lovell (1937) although the importance of the disease had been recognized much earlier. For example, severe criticisms were made of the report by Mettam (1903) that in Ireland the disease was of umbilical origin and associated with pasturella (see Editorial 1903).

Jensen (1897) expressed the view that new-born calves are very susceptible to infection with "colon bacilli"; if a new-born calf is given a small dose of creolin water, pyoktanin solution or the like, a severe enteritis is produced and colon bacilli occur everywhere in the blood and in the organs. He supposed that the injured intestinal epithelium allowed invasion by the ordinary colon bacilli, which a few hours after birth are already present in the alimentary canal. The contributions of this author towards the aetiology of white scours were valuable guides to future work and in 1897 he recorded "if calves are given boiled milk on the first day after birth by far the greater number of them will die from an acute diarrhoea; if, on the other hand, colostrum is fed to them on the first day, the calves tolerate the boiled milk fairly well later on". He regarded white scours as being dependent "on a bacterium occurring everywhere, which sometimes caused sporadic cases of disease, sometimes acquired a transient increased virulence and then caused small enzootics which quickly disappeared of themselves, and sometimes acquired a constant greater virulence and then caused enzootics lasting for years".

It was clearly advantageous to identify and if possible to classify those strains of *Bact. coli* which had been isolated from diseased calves. It would enable special races to be detected, if they exist and also whether one or more strains dominate the bacteriology of a particular herd or area. Joest (1903) found a lack of cross protection with sera prepared against different strains and that biochemical tests were of limited value. Smith, T. (1928) had evidently considered serological methods for classification purposes because he expressed some doubt of the value of identifying the capsular material of strains of *Bact. coli* for this purpose. The strains of *Bact. coli* isolated from calves by Lovell and Hughes (1935) were studied and reported on by Lovell (1937); he also observed the rapid mutation recorded by Smith and Bryant (1927). Many strains of *Bact. coli* exhibit two types of colony, a low convex mucoid sticky one with an entire edge formed by capsulated bacteria and a grey translucent one formed by non-capsulated organisms. Mutation from mucoid to grey occurs readily, and by alkali treatment (see D. E. Smith, 1927) specific soluble substances may be obtained from both kinds although the amount from the grey mutants is usually less in quantity and less specific. Lovell (1927) prepared sera by the inoculation of rabbits with whole cultures and, using a precipitin test as a method of classification, he was able to place strains into specific groups. It was concluded that special races of *Bact. coli* pathogenic for calves exist, though more than one race may be present in a herd.

Attempts have been made in the field of human medicine to classify *Bact. coli* on antigenic grounds. Kauffmann (1947) based his classification on the identification of heat-resisting "O" somatic antigens, the "H" flagellar antigens in motile forms and the presence of capsular somatic "K" antigens. Some years earlier, a "Vi" or virulent antigen of *S. typhi* had been described by Felix and Pitt (1934). This

antigen is apparently a surface component of the bacterial cell and its association with virulence was confirmed by the demonstration that antibodies specifically directed against it confer protection on animals experimentally infected with "Vi" strains (Henderson 1939). Labile somatic antigens similar to the "Vi" antigen of the typhoid bacillus are now known to occur in some other salmonella. The serological classification of *Bact. coli* is very largely dependent upon the principles elucidated in the work done with the salmonella group. A similar pattern emerges although there is some controversy concerning the surface components, known as "Vi" antigens in the Salmonella Group and "K" antigens in the Coli Group. Kauffmann (1947) stated that Smith and his collaborators worked with capsular bovine strains which segregated acapsular forms. Furthermore Kauffmann (1947, 1954) overlooked the work of Lovell (1937) on the surface antigens of *Bact. coli.* He included the "Vi" antigen with the group of "K" antigens which are either envelope or capsular antigens and they have been designated "A", "B", "L", "Vi", etc. This suggests a sharp line of demarcation which probably does not exist and it is better that the capsular and envelope antigens should be grouped under the term "K" antigen. The "A" antigens are the thermostable ones associated with capsules whereas the "B" and "L" antigens are thermolabile and are not associated with morphological capsules. According to Kauffmann there are sufficient differences to warrant their separation and this was challenged by Felix (1952) who considered that the criteria of "K" antigens as formulated by Kauffmann & Vahlne (1945) are exactly the same as those of the classical "Vi" antigen of *S. typhi*; furthermore the basis on which the "L", "A" and "B" antigens of *Bact. coli* have been differentiated was stated by Felix to be invalid, the so-called differences being probably conditioned by other constituents of the bacterial cell, which may or may not, be antigenic. Notwithstanding this, Kauffmann (1954) reproduced and amplified his "diagnostic antigenic scheme (according to Kauffmann-Knipschildt-Vahlne)". There are 126 "O" Groups, most of which are subdivided into several types according to their "K" and "H" antigens. There are, so far, 62 "K" antigens, "L", "A" or "B", and 34 "H" antigens.

The ecology of *Bact. coli* and the significance of its presence may be studied more exactly by these serological methods of classification and identification. Although it is inadvisable to argue from man to cattle, the studies of the coli-flora of the human intestine by Sears, Brownlee and Uchiyama (1950) and by Sears and Brownlee (1952) are interesting and informative. They found that the same serological type of *Bact. coli* may persist in the human intestine for relatively long periods of time whilst other types maintain a tenure for a few days or weeks only. The so-called "resident" strains may become established in the intestines of babies as early as 10 days after birth. Twins and babies which are intimately associated may share the same residents as well as those strains which are transient. A complete change of environment may be accompanied by a change even in the so-called resident strains of *Bact. coli.* This latter observation may have an important bearing upon the thesis developed later in this review that the inherent danger in a change of environment of a mother in the later stages of pregnancy, or of a calf shortly after birth, lies in the possible change in the bacterial flora to which the calf is exposed.

The component antigens bear some relationship to certain characteristics of the bacterial cell; the "K" antigens are associated with invasiveness and the "O" antigens with the toxicity of the strain. Kauffmann (1943) suggested that some "O" groups are more toxic than others and Ewertsen (1946) considered that there is a correlation between a particular "O" group, "O" inagglutinability, the origin of a strain, toxicity, haemolytic activity and the ability to cause necrosis. This is in accordance with general principles of serological analysis and antigenic structure. For example, "O" inagglutinability is dependent upon the presence

of a capsule or envelope and the "K" antigens are associated with invasiveness and with the resistance to the bactericidal effect of serum and to phagocytosis. Those types with genuine capsules are particularly resistant; the haemolytic activity possessed by some strains is apparently a transient characteristic and has not been studied sufficiently. It is however clearly apparent that some of the serological types of *Bact. coli* possess a particular pathogenicity for man and animals. In 1948 Kauffmann advanced the theory that certain serological types played the main role in the aetiology of appendicitis in man. This is in substance similar to the hypothesis concerning *Bact. coli* and white scours in calves (see Lovell 1937). It is now justifiable to assume that some serological types of *Bact. coli* are associated with white scours in calves, with diarrhoea in babies, and maybe, with bovine mastitis. The types labelled in Kauffmann's schema as 111: B4, 55: B5, 26: B6, and 86: B7, are implicated in infantile diarrhoea. Fey (1953) reported the occurrence of strains belonging to these four "O" groups in cattle, especially in cases of bovine mastitis, and there are records of the isolation of a strain of "O" group 26 from white scours in calves, and strains of "O" group 55 from a bull and a chicken. During 1945-47, Wramby (1948) had already taken advantage of the work of Kauffmann, Knipschildt and Vahlne to apply the serological methods of classification to strains of *Bact. coli* isolated from white scours in calves. He examined 4,262 strains from cases of calf colisepticaemia and 1,699 from healthy calves. He confirmed the observations that there is no constant agreement between fermentation and serological type of *Bact. coli* and that strains from calf septicaemia may belong to the same "O" group as strains from normal calves. On the other hand the frequency of the "O" groups in the two types of material examined, varied. Those "O" groups designated 4 and 41 W (now 78) occurred in cases of septicaemia only, whilst "O" group 9 was recovered much more frequently from cases of septicaemia than from normal calves. The most frequent "O" groups in both classes were 8, 15, 9, 30 W (now 117) and 13. The *Bact. coli* flora appeared to be more homogenous in cases of septicaemia and this agrees well with our present concept, namely, that one dominant strain may be responsible for killing calves in a herd or area. The types most frequently responsible for the fatal outcome in calves appeared to belong to 8:20, 8:24, 9:30, 15:10 and 54:28. The aetiological significance of strains of *Bact. coli* in white scours in calves as well as in some forms of diarrhoea in babies would seem to be established.

Although the terminology so far used is that commonly accepted by bacteriologists in Great Britain, there is the probability that *Bacterium coli* will in future be known as *Escherichia coli*. The Enterobacteriaceae Sub-Committee of the Nomenclature Committee of the International Association of Microbiologists (see Report 1954) regarded the Enterobacteriaceae as "A large family of Gram-negative, non-sporing rods, either motile with peritrichous flagella or non-motile. They grow on ordinary media and ferment glucose rapidly with or without gas production. They reduce nitrates to nitrites." The Escherichia group are "A large group of serologically related Gram-negative and non-sporing rods showing with certain exceptions, a motile peritrichous phase in which they normally occur. They commonly form indole and give a negative Voges-Proskauer test, but a positive Methyl Red reaction. They do not decompose urea and usually they do not grow on Simmons' citrate agar. Gelatin is not liquified. Lactose is usually fermented. The subdivision of this group into serotypes is . . . . according to Kauffmann, Knipschildt and Vahlne. The single serotypes have no special names, but are characterised by their antigenic formula." The antigens are "O", "K", "H", the "O" being the thermostable somatic antigens, the "K" are the envelope or capsular antigens and the "H" the thermolabile flagellar antigens. "L" and "B" are thermolabile "K" antigens and "A" thermostable "K" antigens. In the report cited a table was given of some of the serological types associated with

enteritis in babies and as an example of the serological classification of *Bact. coli* it is reproduced below:—

TABLE NO. 3

Examples of Notation Given to Serological Types of *Bact. coli* associated with Diarrhoea in Babies

O	*K*	*H*
111	B4	2 12
55	B5	2 6 7
26	B6	11

O = somatic antigens which are numbered in arabic figures.
K = surface antigens which are designated L, B or A with an arabic figure.
H = flagellar antigens, also numbered in arabic figures.

Since this report was issued, other serological types have been known or suspected to have been implicated in infantile diarrhoea.

The Significance of Colostrum. The value of colostrum to the new-born calf is appreciated and some authors have stressed the importance of its antibody content; others have paid greater attention to its vitamin content—vitamin A and some vitamins of the B complex have been credited with playing some part in the prevention of scours in calves (Phillips, Lundquist & Boyer 1941, Lundquist & Phillips, 1942, 1943). From 1949 onwards a series of papers has been published by workers at the National Institute for Research in Dairying, Reading, and the Royal Veterinary College, London, on the "Nutritive Value of Colostrum for the Calf". A study of the effect of different fractions of colostrum was recorded in the first paper (Aschaffenburg, Bartlett, Kon, Terry, Thompson, Walker, Briggs, Cotchin and Lovell, 1949). Whereas vitamin A is contained in the fatty fraction of colostrum, antibodies are present in the aqueous phase. The value of these fractions, in the diet of calves, was compared and some of the data given are reproduced below. They indicate that only those calves whose initial diet contained the aqueous phase of colostrum made satisfactory progress; other calves failed to grow and many of them died. Those calves which died were examined *post mortem* and *Bact. coli* was recovered from the blood and bone marrow of a high proportion of them. The interest in this class of experiment lies in the methods employed and the achievement of significant results without recourse to deliberate infection. Male calves had been obtained from tubercle-free herds and were removed from their dams at birth; they were dried and transported within a few hours from the farm, where they were born, to experimental calf pens. Every effort was made to ensure that calves had not had access to colostrum and in later experiments this was verified by subjecting the serum of the new-born calf to a simple zinc-sulphate turbidity test (Aschaffenburg 1949). The new-born calves were placed in pens selected at random and, although this was not expressed sufficiently strongly in the records, it was soon realized that white scours or colibacillosis developed spontaneously in the experimental pens. These events were, without doubt, conditioned by the fact that some calves in each block were denied colostrum or its protective fraction. A few preliminary experiments had shown that the calves

which had received colostrum for the first four days of life were able to survive and grow normally on the "synthetic diet" provided. If this diet were given to calves deprived of colostrum a high mortality ensued.

TABLE NO. 4

Performance of Ayrshire and Shorthorn Calves on Different Treatments

(*calves "subjected to the experimental conditions in which spontaneous outbreaks of white scours developed"*)

	Treatment		
Calves of both breeds.	*Clarified fatty fraction of colostrum.*	*Non-fatty fraction of colostrum.*	*Whole untreated colostrum.*
Number used	8	16	11
Number died	4	1	0
Mean live-weight gain in lbs. of surviving calves during 21 days	8 ± 3.3	14 ± 1.5	13 ± 1.9

[*Reproduced from Aschaffenburg* et al., (1949 *a*)]

A further paper (Aschaffenburg *et al.* 1949 b) showed that the non-fatty fraction of colostrum in such small quantities as 80 ml. sufficed to protect calves from a fatal attack of white scours and that the protective factor withstood heat at 63°C. for half an hour. Attempts were made to define this protective factor more closely and comparisons were made with colostral whey, dialysed whey and the "immune lactoglobulins"; these latter substances are prepared by the removal of casein followed by dialysis of the proteins precipitated by 0·4 saturation with ammonium sulphate. It was assumed, by assay of brucella agglutinins, that any antibodies against *Bact. coli* present in the colostrum would be present unimpaired in the "immune lactoglobulins" fraction. All of eight calves deprived of colostrum died from a *Bact. coli* septicaemia, three of eight given 200 ml. of separated colostrum also died from a *Bact. coli* septicaemia. Of eight receiving 14 g. "immune lactoglobulins" three died from a *Bact. coli* peritonitis and pleurisy. These results (Aschaffenburg *et al.* 1951 a) taken in conjunction with the others recorded in this paper and with the earlier work show that under the conditions of the experiments the survival of the new-born calf is dependent upon a factor contained in the globulin fraction of colostrum. The work so far reported suggested that this factor, namely the globulin constituents of the aqueous phase of colostrum, exerted its influence because of its immunological nature. An investigation into the immunological aspects of the protective action of colostrum was therefore made. This necessitated a study of the antigenic structure of those strains of *Bact. coli* isolated from calves that died in the experiments already recorded. It was essential that this information be available as it was to form the basis of the immunological study. These combined observations were recorded by Briggs (1951) and by Briggs *et al.* (1951). Sera were prepared in rabbits, and precipitin tests made with alkali

extracts of the strains. The results were compared with those obtained from agglutination tests, agglutinin absorption tests and mouse protection tests. There is clearly a close relationship between the precipitin reaction and the agglutination of the "K" antigen of a strain of *Bact. coli*. The results of the protection tests in mice showed that a serum containing the precipitin and the antibody against the "K" antigen of a given strain of *Bact. coli* protected mice infected with that strain. The evidence of the close linkage between the "K" antigen-antibody reaction and the protective activity of a serum provided the basis for this immunological study of the protective value of colostrum.

Samples of colostrum were treated with rennet and whey fractions prepared. Agglutination and mouse protection tests showed that whey from colostrum could be examined in the same way as immune sera; the "K" antibody content of colostrum and its protective activity in mice were closely related. Colostrum containing agglutinins against the "O" antigens alone, afforded little protection and a sample which did not contain agglutinins against either type of antigen had no protective value. It was therefore argued that the protective value of a sample of colostrum against a given strain of *Bact. coli* could be estimated by ascertaining its titre of "K" antibody.

During 1949 (see Briggs *et al.* 1951) an epidemic of white scours occurred in the experimental pens; calves given colostrum and expected to live, died, as well as those deprived of colostrum. Not more than three or four serological types of *Bact. coli* were responsible for this epidemic. Four samples of colostrum had been bulked for feeding calves and these were tested for agglutinins against the "K" antigens of the *Bact. coli* which had killed the eleven calves receiving the colostrum. With possibly one exception, no agglutinins against the relevant "K" antigens were found in any of the four samples of colostrum. The relationship between the protection of young calves by colostrum, and the presence in the colostrum of agglutinins against the "K" antigens of *Bact. coli* adds some weight to the view that the protective action of colostrum is immunological in nature. The colostrum given to these eleven calves which died from white scours was deficient, with one possible exception, in agglutinins against the "K" antigens of the strains recovered from the dead calves. There was, in another experiment, some evidence that calves receiving colostrum that contained agglutinins against relevant "K" antigens survived exposure to *Bact. coli* which killed calves not given colostrum in the same environment. It was admitted that the evidence was incomplete but it is suggestive of the immunological nature of the protective action of colostrum. Furthermore, it is probably associated with the possession of antibodies to the "K" antigens of the infecting strains of *Bact. coli*.

More evidence was presented in a report made by these authors to the XIIIth International Dairy Congress at The Hague in 1953 (see Ingram *et al.* 1953 b). The data given included the experiences over the seasons 1950-51 and 1951-52. Calves had been collected and managed as before and no calf was accepted into the calf pen unless the globulin turbidity test (Aschaffenburg 1949) showed that it had not ingested colostrum. The calves were kept on a "synthetic milk" containing 9·5 per cent dried skim milk, 2 per cent non-vitaminized margarine and 2·5 per cent glucose in water; 3,500 I.U. vitamin A and 700 I.U. vitamin D were given daily to each calf. Each group of four to six calves included at least one deprived of colostrum and the others were given small quantities of fractions of colostrum; white scours developed spontaneously. The value of colostrum to the new-born calf was again demonstrated and the fate of 264 new-born calves is given in the following table:—

TABLE NO. 5

Fate of 264 New-Born Calves Given, or Deprived of Colostrum

(*"calves were subjected to experimental conditions under which white scours occurred spontaneously."*)

	CALVES		
	Survived	*Died*	*Total*
Received colostrum	118	43	161
Deprived of colostrum	9	94	103
	127	137	264

[*See Ingram* et al., (1953 *b*)]

All the samples of colostrum were tested for agglutinins against strains of *Bact. coli* and the following data abstracted from the results have some bearing on the problem.

(a) Samples of the colostrum given to 118 calves which survived were tested for agglutinins against the strains of *Bact. coli* that killed 94 calves deprived of colostrum. Sixty-three of the 94 strains of *Bact. coli* were agglutinated by the colostrum and traces of agglutinins against a further 9 strains were observed. Thus, a very high proportion of these samples of colostrum contained agglutinins against those prevalent strains of bacteria.

(b) The colostrum given to 43 calves that died in spite of this treatment, was tested against the strains of *Bact. coli* which killed them. Three of the 43 strains only were agglutinated and this is in marked contrast to the results obtained with those from the colostrum-fed calves that survived.

The combined evidence is therefore that the factor in colostrum which is essential for the new-born calf is contained in the aqueous phase and more particularly in the fraction known as immune lactoglobulins. These are associated with the specific antibodies against the prevalent and potential pathogens and there is now evidence of the essential specificity of the protective factor in colostrum. Although special races of *Bact. coli,* which are pathogenic for calves exist, this concept of the aetiology of white scours is undoubtedly correct. White scours is the result of a shifting of an equilibrium in favour of *Bact. coli*; whether invasion of tissues and death of the calf occurs depends upon the virulence of a particular strain and upon factors associated with the host. Lack of colostrum or delay in obtaining it is one of the important factors and it is now clear that the specificity of that colostrum is of prime importance. Errors in feeding may also act unfavourably and Sheehy (1934) suggested that digestive disturbances in calves may frequently be traced to abnormal curd formation in the fourth stomach.

It has been recorded that some breeds of cattle are more easy to rear when deprived of colostrum than others and this suggests a breed susceptibility to white

scours. Using Holstein calves, that had been deprived of colostrum, Lundquist & Phillips (1943) succeeded in rearing them on a skim milk diet supplemented with vitamins A, C, D, and nicotinic acid, whereas similar attempts with Guernsey calves failed. In their experimental work Blakemore *et al.* (1948) found Ayrshire and Jersey calves more susceptible to white scours than British Friesian calves. This induced Aschaffenburg *et al.* (1952) to compare the performance of Friesian and Shorthorn calves in their experiments concerning the nutritive value of colostrum. Twelve Shorthorn and 12 Friesian bull calves were deprived of colostrum and fed a standard diet based on dried skim milk. Eleven calves of each breed died and there were no differences in the mean age at death or in their performance. There is therefore insufficient evidence at the moment to determine the part which breed plays, if any, in the aetiology of white scours. It is sufficient at the moment to regard white scours or colibacillosis as the penalty paid by the calf when an equilibrium is disturbed. This disturbance may be determined by the virulence of the organism, by factors associated with the host or by a combination of both.

The Specificity of Colostrum. It has been asserted that colostrum acts in virtue of its vitamin content, especially vitamin A. Calves born to cows with a low content of vitamin A in the colostrum were more liable to infections such as white scours than were calves from cows whose colostrum had a higher vitamin A content. (Stewart and McCallum 1938). This is attractive reasoning because vitamin A has a bearing on the protective mechanism against bacterial invasion and is stored whilst the cow is at pasture; it is lost during winter feeding and it is suggested that this may account for the seasonal influences in calf mortality. This means that a winter pregnancy would be followed by a low vitamin A content of the colostrum. It has been shown that the vitamin A content of the blood plasma of calves is low at birth and that a five-fold increase may occur after colostrum is taken (Moore and Berry 1944). On the other hand it has not been found possible to influence the vitamin A content of colostrum by feeding carrots and cod-liver oil to cows during the later stages of pregnancy. Attempts made to influence the incidence of white scours by giving vitamin A concentrates direct to calves at birth did not prove satisfactory (Grieg 1943). The addition of 150,000 I.U. vitamin A during the first two days of life to the diet of calves deprived of colostrum did not protect them from death under the conditions to which they were exposed in the experiments of Aschaffenburg *et al.* (1949). In later work (Aschaffenburg *et al.* 1953) it was demonstrated that the feeding of vitamin A with or without lecithin had no significant effect on scouring, on the temperatures of the individual calves or on their growth rate. In some cases the feeding of lecithin and vitamin A increased the liver reserves of vitamin A significantly. The crucial result obtained concerns those calves which were deprived of colostrum; all these died even when they had received lecithin and vitamin A.

The synthesis of the B complex may be inadequate in the new-born calf and there may be a delay of a week or so in the formation of vitamin C.

On the other hand the evidence so far presented is strongly in favour of the immunological specificity of the protective factor in colostrum. It is not denied that the protein content and the vitamin content may have some protective value. The main and significant factor however is that associated with the antibody content. The presence of antibodies against the surface antigens of the strains of *Bact. coli* to which the calf is exposed is an indication of its value. It follows that a calf, having received colostrum, may suffer from an infection with *Bact. coli* because the colostrum provided does not contain the specific antibodies. It is therefore dangerous to change the environment of a calf shortly after birth; the passive immunity it enjoys may not be of value in the new environment where it may be subject to the risk of infection from bacteria which are different from

those which immunized its mother. It follows also that the well-being of the calf might be impaired if the environment of the dam should be changed before parturition; the colostrum may contain antibodies against those potential pathogens prevalent in the neighbourhood in which the mother has been living, but not against those in other environments. These are factors which should be considered when planning special buildings and yards for parturient cows or new-born calves.

A dairy practice known as "prepartum milking" has a vogue in some quarters; it consists of milking cows and heifers before parturition, in order to reduce the congestion of the udder and increase the milk yield. The extent of pre-milking varies widely from farm to farm; some cows are milked once or twice before parturition and others for about a month before. It is possible that this *post-partum* secretion of pre-milked cows may be of less benefit to the calf than normal colostrum. Hill, Widdowson & Maggs (1950) concluded that the practice of pre-milking under practical conditions is not detrimental to the health of the cow or calf. In their records, it appears that pre-milking was frequently restricted to the two or three days before calving and under these circumstances the secretion may differ little from normal colostrum. A study of the effect of prepartum milking on the calf was made by Aschaffenburg *et al.* (1951 b) who gave groups of calves during their first 24 hours of life, colostrum, the *post-partum* secretion of pre-milked cows, or milk. The *post-partum* secretion was obtained from Shorthorn cows which had been pre-milked twice daily for 16 ± 1 days before calving; this secretion and colostrum had been obtained from these and other Shorthorn cows within 24 hours after parturition. Shorthorn bull calves were collected and managed as in all other experiments by these authors. Of six calves receiving colostrum, none died; two of six receiving milk died from a *Bact. coli* infection and three of six receiving the *post-partum* secretion of pre-milked cows died. The mean live-weight gain at 14 and 21 days, adjusted for birth weight, of calves that had received normal colostrum was significantly greater than that of calves on the other two treatments. The poorer performance of the calves is linked with the decline in the agglutinin content of the secretions and the authors expressed doubt as to whether new-born calves would, under these circumstances, get as good a start in life as those receiving normal colostrum. It is probable that under normal farming conditions pre-milking would be restricted to the relief of congestion of the udder on the last day or two before calving; the calf would then receive *post-partum* secretions differing little from normal colostrum. It is also likely that the calves in this experiment were exposed to a greater risk of infection than would occur under normal farm conditions.

Summary. Aetiology is the science of causes of a disease and a multiplicity of factors may be concerned. In white scours, the specific organism, usually *Bact. coli,* is capable of killing calves under certain conditions. The identification of strains of *Bact. coli* by serological means is being used successfully in calf diseases and in some human diseases, such as infantile diarrhoea. This identification and classification is dependent on the recognition of heat-resisting "O" somatic antigens, capsular somatic "K" antigens, and to a less extent "H" flagellar antigens in forms which are motile. The "K" antigens are either envelope or capsular antigens and some claim is made for their separation into "A", "B" and "L" forms according to an arbitrary heat-stability; this separation is, according to one author, not warranted. The diagnostic scheme of Kauffmann-Knipschildt-Vahlne includes 126 "O" groups which are subdivided according to their "K" and "H" antigens. It appears that, based upon this type of analysis, some serological types of *Bact. coli* are particularly associated with white scours in calves. Some of those types associated with infantile diarrhoea are well defined and are adequately labelled and an example is given of the type of label given to some of them.

The supply of colostrum to the new-born calf is of prime importance and the results obtained by many workers supply sufficient evidence that the lack or inadequacy of it is a factor in the aetiology of white scours. The non-fatty fraction of colostrum contains this protective factor and further analysis points to its presence in the "immune lactoglobulins". Another approach made to identify this factor was along serological lines and colostrum which protected calves against particular strains of *Bact. coli* tended to contain agglutinins against the "K" antigens of these strains; in general the reverse was also true. It had already been proved that these agglutinins were correlated with those antibodies which could be demonstrated by precipitin tests and by mouse-protection tests.

White scours is therefore the result of a shifting of an equilibrium between the young calf, the host, and the bacteria, *Bact. coli*. This upset is in favour of *Bact. coli*, and invasion of the tissues, followed or not by death, depends in part upon the virulence of the particular strain of *Bact. coli* and in part upon factors affecting the host. The lack of colostrum is a contributing factor and it is now clear that the character of the colostrum in terms of immunological specificity is equally important.

The proven fact that it is the immunological specificity of colostrum which is primarily important in the protection of the calf points to some dangers in methods practised in calf management. The change of environment of a calf shortly after birth is a hazardous procedure because the animal meets bacteria against which it has no immunity. Its immunity is dependent largely upon the colostrum it receives and may be of no avail against bacteria in the fresh environment. It is equally hazardous to change the environment of the cow shortly before calving; the colostrum which would be of value in the old may not be of value in the new neighbourhood. The potential calf-pathogens in the cow's original environment would have stimulated the cow to produce adequate antibodies for its offspring's protection; this protection may be valueless against other strains and types of bacteria which the calf meets when transported to a new environment just before or just after birth. The same argument may be directed against the practice of "pre-partum" milking; the secretion available for the calf at its birth may cease to have the characteristics and value of colostrum in a cow "pre-milked" for some days.

THE PATHOLOGY OF *BACT. COLI* INFECTION IN CALVES

According to Smith and Orcutt (1925) there is a quantitative relationship between *Bact. coli* and the normal and the disturbed intestinal tract of the calf. These authors suggested that these organisms were probably present at all levels of the small intestine and that in white scours, there was an increase in the number of *Bact. coli* in the lowest third of the small intestine. The invasion tended to spread towards the duodenum as the disease gained headway and there was a general intoxication of the calf. The bacteria were in the form of layers or films and attached to the epithelial cells. The gross pathological changes are, however, small; there may be an enteritis and the intestinal lymph nodes are occasionally enlarged. The lungs invariably show some congestion and possibly necrosis (Lovell & Hughes 1935).

The disease is frequently a septicaemia and *Bact. coli* are present in the bone marrow and blood stream. Some preliminary work has been done on the nature of the toxic factor responsible for the so called intoxication and for the death of the calf. Attempts were made to extract from strains of *Bact. coli*, antigenic substances similar to those described by Boivin *et al.* (1936). Suspensions of *Bact. coli* were prepared from mucoid strains and the centrifuged mass treated with an equal amount of N/2 trichloracetic acid; the supernatant fluid was dialysed

against tap water and the resulting fluid constituted the "antigen complet" of Boivin. It had a pH of 7·5 to 8·0 and a precipitate was formed when mixed with specific antisera. Intraperitoneal injection of this preparation into mice induced diarrhoea, increased respiration and a ruffled appearance of the coat. A toxic effect was induced in rabbits by injection of the substance intravenously; those which recovered possessed specific precipitins in their blood. A marked reaction was induced in calves by the injection of as little as 1 ml. intravenously; death occurred within an hour or two preceded by greatly exaggerated respirations and the discharge of copious froth from the nose and mouth. There is therefore some evidence that the toxic substance, probably a polysaccharide linked to a fatty acid, may itself induce intestinal and other disturbances. The diarrhoea may not be caused by a local irritation but by the toxic products of *Bact. coli* which are present in the blood, spleen, bone marrow and other tissues (Lovell & Hughes—unpublished).

The clinical picture of profuse scouring, high temperature, dehydration, prostration and death is associated with a septicaemia and the findings *post mortem* are not marked. Some calves, and especially those which die in spite of receiving colostrum, exhibit a localized intestinal infection only.

Summary. The pathological changes in the individual calf dead from white scours are not marked. There is frequently a septicaemia, and the diarrhoea may be associated with some toxic products of the bacteria and not necessarily be due to any local irritation in the intestines.

EPIDEMIOLOGY OF WHITE SCOURS

In an Enclosed Community. Smith & Little (1922) had suggested that the bacterial flora varied in different herds and that some strains of *Bact. coli* tended to predominate. This view was based on the isolation of special biochemical types from a series of dead calves. There was some support for this view in the report by Lovell (1937) who by means of a precipitin test, showed that many strains of *Bact. coli* recovered from the tissues of dead calves were serologically similar, and that one or two strains might predominate in a herd. The studies made by Briggs (1951) confirmed the close relationship existing between agglutination of the "K" surface antigens, precipitation of immune sera by alkali extracts of the bacteria and the protection of mice by immune serum. Strains of *Bact. coli* were identified by these means as well as by simple agglutination tests for determination of the protective value of colostrum. During the seasons 1950-51 and 1951-52 it was therefore possible to study the epidemiology of white scours in calves in an enclosed community in greater detail because of the availability of these techniques. Calves were collected from surrounding farms and some in each block were denied colostrum; the cultures of *Bact. coli* obtained from dead calves were examined by biochemical and serological methods. The common organisms recovered were the faecal type 1 of *Bact. coli*; immune sera were prepared against selected strains and the identity of the somatic "O" and surface "K" antigens determined. A number of defined serological types of *Bact. coli* were therefore established and these were recovered from time to time.

The following table gives the relevant data concerning the serological types of *Bact. coli* recovered from 137 calves which died during those two seasons; see Ingram *et al.* (1953 a) and Wood (1955) in a thesis. Eighty-four died during the 1950-51 season and 53 during 1951-52; the serological types of *Bact. coli* have been given a number preceded by R.V.C. without prejudice as to any agreed method of classification although where possible the relevant antigenic formula given by Kauffmann (1954) is indicated:—

TABLE No. 6

The Antigenic Structure of Strains of *Bact. coli* Isolated from Calves
[*Modified from Ingram* et al., (1953 *a*)]

Season	*Strains of Bact. coli (Serological type)*	*Antigenic Structure* "O" (See Kauffmann (1954))	"K"	*Number of dead calves from which isolated*
1950-51	R.V.C. 51	114	—	13
	,, 57	—	—	3
	,, 58	—	—	2
	,, 95	26	B6	7
	,, 101	35	L	18
	,, 118	9	A	13
	R.V.C. 101 & 118	—	—	2
	Not defined	—	—	26
1951-52	R.V.C. 330	78	B	11
	,, 118	9	A	16
	R.V.C. 330 + ?	—	—	5
	,, 118 + ?	—	—	3
	,, 118 & 330	—	—	1
	Not defined	—	—	17
	Total			137

"+ ?" = and another strain not defined.

The antigenic notation is given to those strains which have been identified as falling within the classification of Kauffmann (1954). "—"=that this antigen has not yet been identified in accordance with this classification.

Although in most of the cases *Bact. coli* alone was recovered from the heart blood of the dead calves this table shows that occasionally more than one strain was isolated from a calf.

Some of the strains examined by Ørskov (1951) and cultures with the antigenic structure of R.V.C. 95. (26: B6) have been recovered from cases of neo-natal diarrhoea of children in Denmark, Finland and England, and from white scours of calves in Sweden and Pakistan (Ørskov 1951, Bokhari & Ørskov 1952, Taylor & Charter 1952). Fey (1953) isolated a strain with this antigenic structure from a case of bovine mastitis; a similar strain was recovered from the faeces of the wife and three children of the farmer and after the successful treatment of the bovine mastitis these strains disappeared from the human faeces. He also found this type in cases of infantile diarrhoea. Strains belonging to O group 114 have also been recovered from babies; some were implicated in an outbreak of infantile diarrhoea and others were recovered from sporadic cases (see Charter 1955).

Figures have been constructed from the data collected from the work of Aschaffenburg and his colleagues at the Royal Veterinary College, London, and the National Institute for Research, Shinfield, Reading to show the time relationship. The life of a calf is shown by a horizontal bar and the type of *Bact. coli* isolated is indicated. Only those calves which died from infection with the defined types are shown.

PLATE I

Calf ill from "white scours": the sunken appearance of the eye is a characteristic sign.

PLATE II

Calf ill from "white scours": typical prostration.

White Scours in an Enclosed Community

FIG. 1

EPIDEMIOLOGY OF 1950–51 OUTBREAK

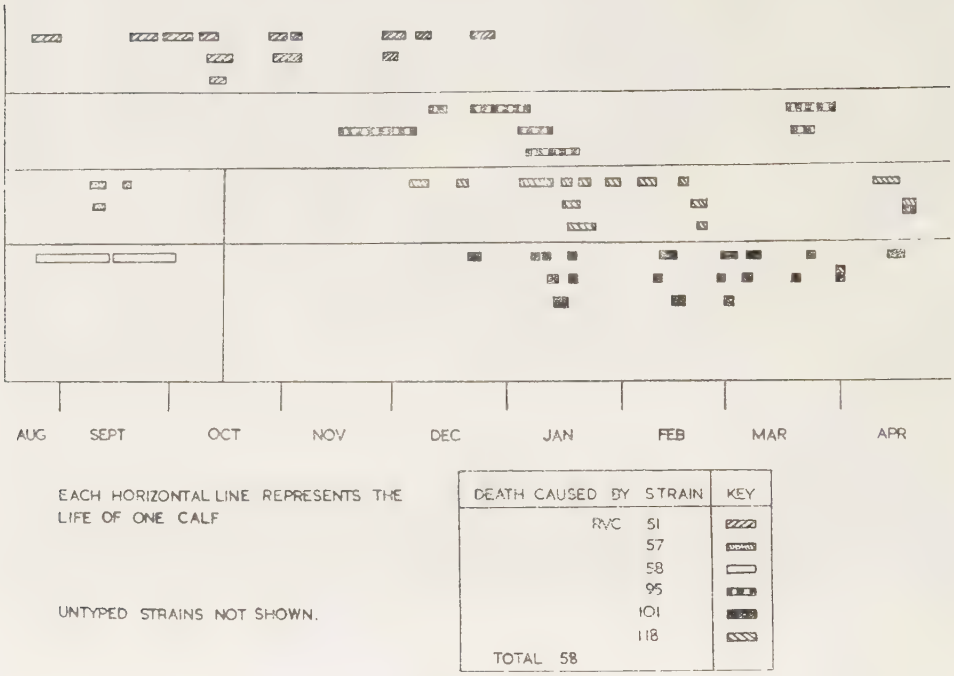
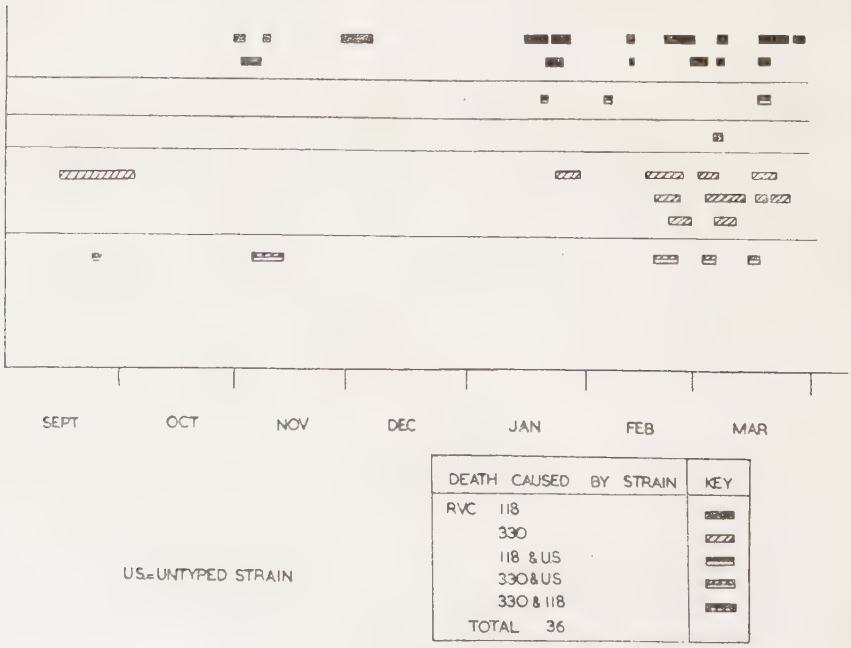


FIG. 2

EPIDEMIOLOGY OF 1951–52 OUTBREAK



(reproduced from Ingram *et al.* (1953 a)

It is abundantly clear from the data displayed that in the season 1950-51 there was a constant change in the bacterial flora. This was in an enclosed community subjected to constant immigration of fresh susceptible calves. One strain of *Bact. coli* was dominant for a time and was then replaced by another. For example, R.V.C. 51 was dominant in the autumn of 1950 and R.V.C. 95, 118 and 101 followed in quick succession even overlapping each other. The host-parasite relationship was undergoing a constant change and this change was influenced by many factors. At the beginning of the season the mortality of calves receiving small quantities of colostrum was low and even some of those deprived of colostrum survived. During the progression of the season, the mortality increased and eventually some of the calves receiving colostrum succumbed. It may be, that the virulence of the bacteria increases during passage from calf to calf; the antibody content of the colostrum, and the quantity given may be important factors as well as the number of calves at risk at any particular time. It is clear from this that the equilibrium which calves acquire with their environment under natural circumstances may be upset violently when calves are collected from several sources and kept together under the conditions described. It is also apparent that the stability of the host-parasite relationship may be disturbed by management. It is hazardous for a calf to be brought into a new environment shortly after birth and it is also dangerous for it to be deprived of colostrum.

In the Field. At the moment, insufficient observations have been made on field outbreaks of white scours using the new knowledge of the classification of *Bact. coli*. Wramby (1948) collected material from carcasses sent to the State Institute of Veterinary Medicine, Stockholm; these came from herds in which white scours was rife. He examined a second group of calves which had shown signs of septicaemia and were from slaughter houses. The cultures obtained were compared with those isolated from healthy calves, but the epidemiological data available in his report are scanty. Wood (1955) gave brief accounts of his study of 56 outbreaks of white scours associated with *Bact. coli* and allied organisms. The common strain of *Bact. coli* encountered was the one designated R.V.C. 330 (78: B); this is the type which has been obtained from the calves kept under experimental conditions and from calves in other countries (Bokhari & Ørskov 1951). Wood also encountered R.V.C. 58; R.V.C. 101 (O 35.L.); R.V.C. 95 (O 26. B6); R.V.C. 118 (O 9.A.); and R.V.C. 383. The epidemic nature could, however, be shown on one farm only, where six calves died from infection with type R.V.C. 330 over a period of four months. Samples of colostrum fed to the calves and the immune sera used for prophylactic purposes were tested for agglutinins against R.V.C. 330 and none were observed. Agglutinins against strains isolated from the rectum of calves which were in contact, were present. Fifteen young calves were bought in the markets and introduced into this herd during the two months when the illnesses were most frequent. There is a calf mortality on this farm of about 20–22 per cent and scouring increases in its incidence during the autumn and until the spring. The conditions on this farm resembled closely those in the experimental station previously mentioned in which calves are brought in from the surrounding neighbourhood (see Ingram *et al.* 1953 a & b). It is important to note that the colostrum did not contain demonstrable antibodies against the prevailing strain of *Bact. coli* (R.V.C. 330; 78 B) a strain which was probably introduced by a calf or calves bought in the market.

Summary. The serological examination of strains of *Bact. coli* and the determination of their antigenic structure enables one to study the epidemiological picture of white scours with greater exactitude. In an enclosed community of calves, which is subject to constant immigration, there is a constant change in the dominant and significant bacterial flora. It is probable that there is a constant introduction of fresh strains of bacteria in these susceptible calves. One strain

of *Bact. coli* apparently plays a leading role for a time and is responsbile for killing a number of calves. This is followed by another serological type and there may be some overlapping; the virulence of the organism may increase or the dosage available may be greater, because there is some suggestion of a higher mortality at the end of the season than at the beginning. There is therefore ample evidence of the upset in the equilibrium between calves and the bacterial flora in their neighbourhood when these young susceptible animals are collected together from different sources. The field studies available are not yet sufficient to enable one to follow similar epidemiological pictures under these natural circumstances. The limited data do, however, point to the frequency of some of the serological types of *Bact. coli* in other countries as well as in Great Britain and to the importance of the immunological specificity of the colostrum available.

OTHER INTESTINAL DISEASES OF CALVES

A specific calf dysentery associated with *Salmonella dublin* may occasionally be confused with white scours. Calves of one week old and upwards may be affected with a septicaemia, a haemorrhagic enteritis and a broncho-pneumonia; necrotic foci may be found *post mortem* in the liver and kidneys. The dangerous animal is the symptomless and apparently healthy carrier cow which may have no history of illness, or may have recovered from an attack. Acute attacks occur in adult cattle but are rare. The disease has a public health importance because of the pathogenicity of *S. dublin* for man.

Calves may suffer on occasion from intestinal disorders due to *Salmonella typhi-murium*. The age incidence is usually sufficient to separate these salmonella infections from white scours, this latter being essentially one of new-born calves.

Some of the respiratory diseases of calves are complicated by intestinal disorders and diarrhoea. These may readily be confused with white scours or colibacillosis. The calf influenzal pneumonia described in Northern Ireland by Lamont & Kerr (1939) and by Gilmore (1939) attacked calves from 2–7 weeks of age whereas the one described by Barr *et al.* (1951) and by Jennings & Glover (1952) occurs in calves of one to two days upwards. The high incidence in January to March coincides with that of white scours and together with the similar age susceptibility adds to the possibility of confusion. The infective agent has been filtered through gradocol membranes of 0·67 μ porosity and, up to the present, the disease has been transmitted to calves alone. There is an inflammation of the lungs and turbinate bones and although primarily a pneumonia, this condition may be accompanied or preceded by a diarrhoea and thereby may simulate white scours. There are undoubtedly subsidiary causal factors such as chilling and those animals which were chilled were more seriously affected. The morbidity and mortality may vary up to 90 per cent and animals that recover are frequently stunted. The feeding of colostrum does not apparently prevent the infection.

A virus enteritis and pneumonia was described by Baker in 1943; calves less than a month old in the Eastern States of the U.S.A. were affected. Recovery soon occurred and the sick animals rarely died if kept under good conditions, but they failed to develop satisfactorily and were not profiatble to keep. The incidence was highest from late autumn to early spring and it has been suggested that there are epidemics every 15 to 20 years. It was concluded that the disease is caused by a filtrable virus which is transmissible to mice as well as calves; the pathological changes revealed *post mortem* are a catarrhal enteritis and a broncho-pneumonia.

Summary. Diarrhoea and dysentery in calves may be caused by bacteria of the salmonella group especially *S. dublin*; the age-incidence is however higher than in white scours.

Some respiratory diseases which may be associated with viruses may be confused with white scours because of the concurrent intestinal disturbance. One condition which may develop in calves upwards of one or two days old, is due to a virus and subsidiary factors such as chilling appear to be important.

ACUTE GASTRO-ENTERITIS IN BABIES

Acute gastro-enteritis may occur in epidemics in maternity hospitals and other institutions where young infants are nursed. It spreads readily in a nursery and causes serious illness and many deaths. It is stated to be more prevalent in maternity hospitals than the number of published papers suggests (Report, 1949). The incidence is much higher in premature than in full-term infants, and breast fed infants are rarely attacked. There may be a high mortality in some outbreaks and rates of 70 to 80 per cent are mentioned. Diarrhoea and vomiting are the characteristic features of the disease; this leads to dehydration which is often serious in those infants of the age attacked, namely after the first week.

Many observations have been made and a variety of bacterial and virus agents implicated. Evidence is however accumulating that one of the diseases is associated with special serological types of *Bact. coli*. Bray (1945) recovered one type from 42 of 44 cases and since then a number of other serological types have been incriminated (Giles, Sangster & Smith 1949, Ørskov 1951, Taylor and Charter 1952, Smith 1953). These have been classified by the Kauffmann-Knipschildt scheme and at the moment O111. B4; O55. B5; and O26. B6. are recognized as being related epidemiologically to the disease in various parts of the world. Sero-types belonging to O groups 25, 86, 114 and 119 are also implicated and it is considered likely that some other types are also involved. It was to be expected that more than one or two types would play a similar role as in the calf disease. Three of the types, O 26, O 114 and O 119 have been recovered from cases of infantile diarrhoea and from cases of white scours.

Five strains of *Bact. coli* isolated by Rogers and Cracknell (1955) from cases of infantile diarrhoea during an outbreak in a children's hospital in the Birmingham area and four strains recovered from sporadic cases of gastro-enteritis in the London area were shown by Charter (1955) to belong to O group 114. With the exception of two strains from the London area, those recovered from human beings differed in their "H" flagellar antigens from those isolated from calf scours.

There is a close similarity in the epidemiological picture of the two conditions and it is too early to decide whether any closer relationship exists. The similarities are however significant in some respects. The same serological type occurs in actual cases of human disease and in those in contact or in those who presumably initiated an outbreak. In institutional outbreaks, there are frequently as many babies without symptoms yet harbouring the organism as there are cases of disease. This in no way invalidates the aetiological relationship but emphasizes the importance of non-specific subsidiary factors as causes of outbreaks. One type may cause enteritis as a sporadic disease and also as an epidemic and Smith (1953) suggested that, for this to occur, a lack of immunity in infants to particular types must be presumed. This lack of immunity has been associated with bottle rather than with breast feeding in spite of the fact that the mode of transfer of immunity from mother to baby differs from that in cattle.

One interesting claim has been made that some of these serological types may be recovered from cases of bovine mastitis (Fey 1953). This raises questions in the epidemiology of the disease concerning the reservoir of infection; at present the evidence is in favour of the importance of human carriers and milk is unlikely to be a major reservoir of the bacteria.

Summary. Acute gastro-enteritis in babies may occur in maternity and other institutions and there is frequently a high mortality. Evidence is accumulating

that some of the outbreaks and some sporadic cases are associated with special serological types of *Bact. coli*. There is a close similarity in the epidemiological picture with that of white scours in calves in that there is in both cases a constant immigration of new-born susceptibles. There are frequently as many babies without symptoms yet harbouring the same serological type of *Bact. coli* as those with the disease itself. It is suggested that subsidiary factors play an important role and that the lack of immunity to special types of *Bact. coli* in certain babies may be important.

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Coccidial and Other Forms of Parasitism in Their Relation to Poultry Husbandry

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In reviewing the ways in which different forms of poultry husbandry may affect parasitism of fowls at least four factors must be considered. *Firstly,* the introduction of parasites into the environment of the fowls and the degree to which such introduction is favoured by the type of husbandry employed. Judging from the wide incidence of coccidial parasitism it may be assumed that no form of commercial husbandry is entirely proof against their introduction. Some forms of husbandry may markedly reduce the chances of large introduced infestations into the vicinity of the fowls. There are, of course, many ways in which oocysts or worm ova can be introduced; mechanically, by dust or by carrier chickens, transfer and intermediate hosts and so on. *Secondly,* once these stages have been introduced does the type of husbandry favour their viability over long periods as well as their development to the infective stages? *Thirdly,* to what extent does the fowl have access to these infective stages? And *fourthly,* to what extent do the types of husbandry encourage the increase of parasitism in the individual and its spread to other fowls?

SYSTEMS OF POULTRY HUSBANDRY

There are, broadly speaking, five main systems used in the maintenance of poultry: (1) Free range which is fully extensive allows for 50–100 fowls to each acre of land. The fowls do not run over the land indefinitely but are transferred from one field to another so that the vacated land can be used for cropping or other purposes. The birds are housed at night. (2) A semi-intensive system in which the fowls are housed in permanently placed solid floor units with attached grass runs. Fifty to one hundred are usually housed in each unit. Two or more runs are usually attached to each house and are used in turn while the others are rested. The recently developed straw-yard system is semi-intensive in character. (3) The intensive method in which the fowls are confined to houses and of which the built-up litter system is an example. (4) The folding-system which uses slatted floor houses with attached runs which can be moved each day on to fresh ground. (5) Wire-floored cages, either laying cages which are concerned with egg production, usually arranged in tiers each cage housing one fowl, or tier brooders for young chickens.

DEVELOPMENT OF PARASITISM

From the point of view of the development of parasitism fowls raised on wire floors have a marked advantage over those maintained on any form of solid floor as they are removed from contact with infective bodies contained in the great bulk of the faeces. Although we will confine our attention for the moment to the coccidia the following remarks apply in general terms to the nematodes as well. The free-range system is used for older fowls which have often developed an immunity to caecal coccidiosis caused by *Eimeria tenella* during their contact with this species as younger birds. Less commonly have they

developed any immunity to some of the other species of coccidia that occur in the intestine. The possible dangers of the fully extensive system can only be assessed when we know something of the time that oocysts may be expected to remain viable on the ground. Studies made in the United States have shown that oocysts can survive in the open for a considerable time, *i.e.* from many weeks to nearly two years. Viability appears to depend on such factors as shade, direct sunshine and vegetation. There are obvious difficulties in the way of pin-pointing the effect of an isolated factor within the complex of field conditions under which most of the studies were carried out.

In the laboratory, attempts have been made to study the effects of such factors as temperature, humidity and dryness on unsporulated and sporulated oocysts.

Temperature alone is only rarely a direct factor to be considered in the destruction of oocysts in an outside environment in Britain except, perhaps, in the severest winters. Although winter temperatures may only rarely destroy oocysts they commonly inhibit or retard the development of unsporulated oocysts to the infective stage and this may play an important part in preserving the susceptibility of birds reared on wire floors and first run on pasture in the early part of the year. The most favourable temperatures for the sporulation of oocysts of *E. tenella* lie within the limits of 26·6° and 32·2°C. and unsporulated oocysts fail to develop if it is cold or hot (Ellis, 1938). Although unsporulated oocysts do not develop in unfavourable temperatures they may survive and proceed to sporulate when favourable temperatures are restored. At a temperature of 16·1°C. or below and at a temperature of 42·2°C. or above no sporulation occurs. Oocysts are killed when kept at a temperature of 42·2°C. for 48 hours (Guilford *et al.*, 1947). Oocysts passed on to cement or dry, unshaded ground do not develop immediately if the temperature is 42·2°C. or above, but may do so later if the night temperature drops to 22·2°C. or below. It appears, then, that a temperature of 42·2°C. acting for 6–12 hours does not prevent sporulation provided the temperature is favourable during the other half of the 24-hour period. Oocysts passed out into a shady, cool environment may sporulate in hot seasons but those that are passed out in cold seasons will often remain dormant until the temperature rises above 16·1°C. Other observers (*e.g.* Ellis, 1938) stated that no sporulation takes place at 37°C. or at 4·4°C. but that sporulation proceeds normally when the temperature is raised to 21·2°C.

Patterson (1933) studied the viability of oocysts of *E. tenella* under various soil conditions; he found that oocysts failed to infect chickens 10 weeks after they had been placed in soil with an original moisture-content of 20 per cent from which moisture was allowed to evaporate at atmospheric temperature. Oocysts in saturated soil held at atmospheric temperature produced infections in chicks after 23 weeks (the maximum period tested). Oocysts in soil under natural conditions of weathering and shaded from direct sunlight, produced infections in chicks after 21 weeks, the maximum period tested. Oocysts under similar conditions, but exposed to direct sunlight for 10 weeks, produced infections. Continuous or intermittent freezing over 12 weeks failed to prevent infections in chickens when the oocysts were administered to them.

The survival of oocysts of *E. acervulina, E. tenella* and *E. maxima* depends on sunlight, shade and vegetation. In Maryland, Farr and Wehr (1949) found that oocysts of *E. tenella* and *E. maxima* in outdoor plots were destroyed in less than a year in all cases. In general, infective oocysts were recovered from plots in part shade and deep shade for a longer period than from sunny plots. Some oocysts in all plots survived the lowest winter temperatures recorded, *i.e.*, one degree Fahrenheit above zero. In Wisconsin it is believed that most avian coccidia are destroyed by winter temperatures (Guilford *et al.*, 1947). In Britain,

infections have been produced by sporulated oocysts that had been exposed out of doors, but in a sheltered position, for 14 months (Horton-Smith, 1947). The number of viable oocysts remaining in soil that has been run over by fowls may be considerable and especially so in situations which often carry a dense population of birds such as those in the vicinity of food and water containers and houses. Unsporulated oocysts passed out on to the ground at the beginning of and during a cold season may not sporulate at once but will sporulate readily as the warmer season sets in. Under field conditions high temperatures or direct exposure to sunlight may produce their apparent lethal effects by desiccation. Desiccation tends to fracture the oocyst wall and release the sporocysts but no work has been done to determine the extent to which the released sporocysts may remain infective and nothing is known of the length of time for which they may remain viable under various climatic conditions. In Britain we have plenty of evidence to show that some infective or potentially infective oocysts will survive on the ground from one year to the next. Delaplane and Stuart (1935) found that the oocysts of mixed species of *Eimeria* survived in soil for a period of 4–9 months following the removal of chickens from the range. In a wooded range oocysts remained viable for 15–18 months.

Free Range System

In the fully extensive system of husbandry fowls, being unconfined, will range widely and this is reflected in the wide distribution of oocysts. The faeces do not accumulate, except in the vicinity of the houses and food and water containers, but are scattered thinly over a wide area. Fowls, at the age at which they are usually on range, have generally acquired some resistance to caecal coccidiosis and, owing to the thinly scattered oocysts of other species of coccidia, only rarely pick up disease-producing numbers except, perhaps, in sites where they tend to congregate, although the numbers may be sufficient to encourage the development of resistance. On the other hand if fowls have been reared under conditions which markedly reduce the intake of coccidia they will be susceptible to infestations with all species; if such fowls are placed on pasture that has been populated by lightly infested "carrier" birds they will either immunize themselves or develop disease according to the numbers of sporulated oocysts available to them and the species to which these oocysts belong.

The Semi-intensive System

The semi-intensive system, in which fowls are confined to houses with grass runs, raises other problems. As the houses have solid floors there will be a danger of oocyst accumulation unless strict cleaning is carried out. The permanent placing of the houses means that the attached grass runs may soon become heavily infected. The whole system lends itself to reinfection as the environment usually favours both the viability and sporulation of oocysts. Owing to the confinement of the fowls the ground population of infective oocysts may tend to increase to dangerous proportions if the fowls are susceptible and the environment is favourable. Although in many respects the use of alternative runs is desirable there will be a carry-over of infection from one run to another by the birds themselves. From what we have learnt of the longevity of oocysts on outside plots it is obvious that a considerable accumulation of oocysts may occur in an occupied run before the oocysts in the vacant run have perished. The fate of the fowls in these circumstances will depend on the species of coccidia present and the number of oocysts with which they are challenged as well as on their own susceptibility or resistance to these challenges.

The straw yard has so far received little attention from the point of view of its effects on parasitism. We know that parasitism does occur and that there appears to be a high incidence of nematode infestations in many cases.

The extensive and semi-intensive systems are such that the fowls may be in direct contact with possible intermediate hosts of tapeworms, *e.g.* slugs, snails, beetles and ants, as well as with nematode ova and coccidial oocysts. The environment into which oocysts or ova are deposited may or may not be suitable for their viability or development. Where an intermediate or carrier host is involved reinfestation of a primary host can only be accomplished when the intermediate host is consumed by the primary host. If the microclimate is unsuitable for an intermediate host which is capable of movement that host will travel to another situation that is suitable. Animals tend to avoid the unfavourable and actively seek the favourable. Therefore in considering the parasitism of fowls by tapeworms, and to some extent by *Syngamus,* a knowledge of the conditions favourable to these intermediate hosts may be of the greatest service in control. The selection of sites may be important. Dry, sandy sites are not favoured by snails or earthworms but ants enjoy a wider range of habit and, in this connexion, it is interesting to note that in certain areas tapeworms of one genus (*e.g. Raillietina*) may be commoner parasites of fowls than those of another genus (*e.g. Davainea*).

The Folding System

Before dealing with the intensive system proper it is convenient to review the folding system as this again utilizes pasture. The parasite problems are similar to those encountered in the above methods although the effects of parasitism may be less pronounced since less reinfection occurs as the folds are moved daily. This system does not isolate the birds from possible intermediate and transport hosts. The daily changes of ground are designed to remove the fowls from contact with coccidial oocysts and nematode ova before they become infective. Oocysts develop into the infective stage within a few days at usual spring and summer temperatures. The ova of *Heterakis* require at least 14 days and those of *Ascaridia* at least 10 days to embryonate. These are minimum times and in nature development may take longer according to the conditions of environment. The success of the system really depends on the interval elapsing between the removal of the fold from one locality and its return to it. From our studies of the resistant exogenous stages it seems that each plot should be vacated for one to two years to ensure that potential infections are reduced to a minimum. Their longevity will depend on the nature of their environment in respect of the factors summarized above. As the houses have slatted floors faeces will accumulate beneath them. Although there is ample evidence that oocysts perish quickly in decaying manure, there is also evidence to show that viable oocysts can be recovered from faeces passed by birds many months previously. From this angle, the faeces that have accumulated beneath a house over a 24-hour period are not sufficiently heaped to produce immediate lethal effects on the parasite stages within their mass. Infected faeces may provide a source of infection for the surrounding ground to which they may be carried by a variety of means. Some oocysts of *E. tenella* in the soil will survive severe winters and are capable of producing disease in chicks when they are placed on the infected soil. If succeeding groups of young chickens are placed on the same ground following the first group, severe cases of acute caecal coccidiosis may develop from the build-up of oocysts. The presence of leaves, grass, etc. will tend to protect the oocysts; some of these will survive a severe winter but will be killed during the hot summer months. In Ohio, Koutz (1950) presented data to show that oocysts of *E. tenella* were infective in soil after 272 days' exposure from September to June. *E. maxima, E. acervulina* and *E. mitis* survived a severe winter and part of a summer in a 322 days' exposure. *E. acervulina* and *E. mitis* survived a year's exposure. The highest temperature recorded during this period from September to June was 89°F. and the lowest was −13°F. In many of these instances it is not always possible to determine with certainty whether temperature itself is exerting a direct effect. "The relative humidity is influenced by the absolute humidity as well as by the temperature. If the water content

of the air remains unchanged, the daily course of the relative humidity is converse to that of the temperature. In the ground air layer, the closer to the ground, the more extreme the temperature variations''. (Geiger, 1950). In many of the observations reported little heed was paid to the general climatic situation.

The Intensive System

When we come to consider intensivism, an example of which is the built-up litter system, in relation to parasitism we are confronted with the complication arising from maintaining a maximum number of birds on a workable minimum of floor space. Should an epidemic of coccidiosis be initiated, its spread may be quick and catastrophic owing to the rapid accumulation of oocysts in the litter. The difficulty of recognizing early symptoms of coccidiosis in individual birds within the flock, with a consequent delay of treatment, is also a contributory cause of serious trouble. Various investigators have studied the effects of different types of litter on coccidia. In the United States Boughton (1939) tested litters of different depths and composed of shavings, sawdust, faecal material and combinations of shavings and faeces and sawdust and faeces to study their influence on sporulation. Drying of the faecal samples in shallow (one inch depth) and also in deep (six inches depth) litters of clean shavings and sawdust did not entirely prevent oocysts from sporulating, but there was a reduction in the potential number of sporulated oocysts. Keeping the faecal samples wet in shallow and deep litter of clean shavings or sawdust did not prevent sporulation in all cases. In contaminated litter, composed of either one part of shavings or sawdust and one part of faeces, which was not artificially moistened, sporulation occurred freely and especially so in deep litter in which the original moisture-content of the fresh samples was not dissipated too rapidly. In contaminated litters which were kept wet, sporulation was slowed down or even inhibited. A litter composed of faecal material permitted sporulation provided it was not excessively wet. In commercial built up litter units a variety of conditions influencing the development of oocysts may exist in various parts of the litter at the same time and it is, therefore, impossible to form any accurate estimate of the extent to which sporulation occurs in the litter as a whole (see also Horton-Smith and Long, 1954). Rapid drying and extreme wetness will reduce sporulation but a limited amount of moisture is favourable. In deep litters which are stirred daily and kept dry oocysts would be exposed to the effects of drying during the early stages of brooding while the litter was still relatively free from faecal material. With an increase in faecal material, the litter would be able to hold sufficient moisture for successful sporulation to take place, especially below the surface. In the United States (Tomhave, 1949) moisture in sawdust litters was varied from 36–50 per cent and compared with peanut hulls containing 14 per cent. Deaths from caecal coccidiosis rose from 1·8 per cent to 6·6 per cent as the moisture increased. Kennard and Chamberlin (1949) concluded that the use of old built-up litter may reduce losses from coccidiosis; they associated their smaller losses with improved nutrition resulting from the production of vitamins and other factors. They also recognized the part which acquired immunity might play in the reduction. Although these authors did not mention the possibility it is probable that the fall in mortality might have been due in part to the destruction of many oocysts by bacterial action and consequent ammonia-production. Built-up-litter implies a continued rearing of successive groups of young chickens on the same litter without change. For a description of the system we can do no better than to quote Koutz (1952): ''The original litter is started on fresh litter, four or five inches deep, of either corn cobs, shavings, straw or other materials and left in the poultry house after the brood is reared; another brood of baby chicks is started on the same litter. None of the faecal material is removed; stirring is recommended if the litter cakes. Some fresh litter may be added as needed. This litter and faecal material is allowed to remain for each successive brood and none is removed until the built-up litter

becomes eight to twelve inches deep. It has also been recommended that hens can be reared on the litter and later a new crop of baby chicks reared on the same litter.'' The term ''built-up litter'' is more self-explanatory than ''deep litter'' and provides a truer picture of the process.

The ''broiler'' industry, a highly intensive form of husbandry, is expanding in Great Britain. ''Broilers'' are young chickens of approximately 12 weeks of age. They are usually reared on deep (*i.e.*, 3–4 inches) litter in contrast to built-up litter. The chickens are killed at about 4 lb. weight. In Great Britain 1–1½ sq. ft. of floor space is allowed for each bird but in America it may be as little as 0·6 sq. ft. per bird. Considerable parasitism may be associated with this system. High infestations of *E. tenella* are probably the greatest parasite hazard in view of the rapid multiplication and high oocyst-production of this species, the age of the chickens and the density of their population on the litter. Gordon & Chubb (1954), in discussing the mortality occurring in one particular broiler plant, analysed the causes of deaths as follows: caecal coccidiosis, 38 per cent; lymphomatosis, both neural and visceral, 16 per cent; intestinal coccidiosis, 5½ per cent. This hazard of coccidiosis may be so great that routine continuous medication of the chickens is often practised throughout the growing period. The litter is usually changed between batches of chickens so that the birds start on litter that is relatively free from infection, or, alternatively, the litter is heaped during the period between depopulation and the introduction of a new batch of chickens. In reference to ''broilers'' in general Gordon & Chubb stated that ''In the United States it has been found that better results, from a mortality point of view, are experienced where a whole group is started at one age and marketed at the same time, when the entire plant can then be de-populated and disinfected than, as is the custom in this country [Britain], where the stock is sub-divided into varying age groups, depending on whether intake and marketing is weekly, fortnightly or at longer intervals. From an epidemiological standpoint this can be readily understood, but in this country at the moment our processing and marketing system is not geared to the American method of production.''

Koutz (1948) showed that oocysts of *E. tenella* survived in new built-up litter and in built-up litter that had been treated with hydrated lime which had been added to keep the litter more friable. He found later (1952) that the ova of *Ascaridia lineata, Heterakis gallinae* and *Capillaria retusa* and the oocysts of *E. tenella, E. acervulina* and *E. maxima* were distributed through the litter. *Post-mortem* examinations carried out on the fowls that had been run on this litter revealed adult worms and coccidia. Koutz (1953) also published results which indicated that coccidia and worm ova were not destroyed by the litter. In cases where the litter had not been populated by fowls for 10 weeks during the coldest part of the winter he concluded that many of the ova and oocysts had been destroyed. Fewer parasites were found in birds placed on this litter than in birds placed on litter that had not been de-populated during this period. He also pointed out that the rearing of young chicks on litter that had been populated by old hens (and had not been heaped, presumably) may constitute a grave parasite problem. Baby chicks run on such litter are exposed to numerous nematode parasites and coccidia with the result that the parasite problem becomes 'almost acute'. Old built-up litter on which only young birds had been reared presented no great problem as far as nematode parasites were concerned but coccidiosis still proved to be one. There are factors present in established built-up litter which will destroy oocysts under laboratory conditions, but the constant movement of the litter, caused by the activities of the fowl population, complicates the whole question in that the environment in which the oocysts occur is in a continual state of ecological change. Temperature of the litter increases as fermentation proceeds and higher temperatures are recorded at the base of the litter than at its surface. These temperatures are often within the range of temperatures required for the optimal sporulation of

oocysts and embryonation of ova. Moisture is necessary to develop heat and it is also essential for the development of oocysts and ova. Low moisture content is of prime importance in controlling the development to infectivity of both oocysts and ova and in many instances parts of the litter may be dry enough to ensure such control. On the other hand, litter frequently contains sufficient moisture to maintain the viability of these stages, as may be demonstrated by infection tests in parasite-free fowls. Also, non-embryonated nematode ova and unsporulated oocysts collected from litter can be developed to the infective stages under laboratory conditions and can then be used to produce infestations in experimental chickens. Although dryness of litter may be, and sometimes is, a potent factor in the control of the exogenous stages of parasites it is not always easily achieved in those cases in which adult stock are run on built-up litter. It must be assumed that this form of husbandry may prove to be a definite hazard as far as parasitism is concerned. The extent to which non-parasitic diseases have been recorded in fowls managed in this way also suggests that built-up litter is not a panacea in this respect. In dealing with the spread of parasitic diseases we must not neglect the changing behaviour of the chickens at different ages. Young chicks do not scratch deeply into the litter and, provided they are carrying parasitic infestation, oocysts and worm ova will tend to accumulate at or near the surface of the litter during the chicks' first few weeks of life and will be available to them. It is no uncommon experience to meet caecal coccidiosis and worm infestations in young chickens on built-up litter. Again, much will depend on the predominant species of coccidia present. Brackett and Bliznick (1949) estimated that for each oocyst of *E. tenella* ingested 100,000 will be produced. *E. acervulina* may produce 35,000 oocysts from each oocyst ingested and *E. maxima* may produce 11,000 and *E. necatrix* possibly 50,000. The oocyst build-up will tend to vary with the species. Heavy inoculations with oocysts will often produce fewer oocysts per oocyst fed than lighter ones. Any dilution effect produced by a litter-faeces mixture will tend to reduce the numbers of oocysts ingested and, within limits, a greater production of oocysts may occur. Relatively non-pathogenic species, *e.g. E. mitis* and *E. praecox,* are commonly met with in built-up litter and, therefore, samplings of litter and determinations of total oocyst counts alone may give a false impression of the disease hazards present. On the whole, we must assume that the built-up litter system may be a fruitful source of parasitism. Heaping of moist litter produces high temperatures which are lethal to the parasite stages within it and is probably the best means of sterilizing the litter of parasites between batches of birds. *Ascaridia, Heterakis* and *Capillaria* are commonly found in built-up litter and the former may become a hazard. Good built-up litter is not usually a source of tapeworm infestation as it is only occasionally that the appropriate intermediate hosts are encountered in it.

Horton-Smith *et al.* (1940) discussed the potent effect of ammonia on coccidial oocysts and suggested that the high concentrations of ammonia attained might have a lethal effect on the oocysts in built-up litter. In the litter ammonia concentrations occur that have been found to be lethal to oocysts in the laboratory and they may exert some control on the coccidial population in built-up litter but certainly not to the extent that was once supposed. Rapid reduction of ammonia may arise through the disturbance of the litter by the fowls or through a drop in the hydrogen ion content of the litter itself. These and other factors in their relation to oocysts and ova were discussed in a preliminary way by Horton-Smith and Long (1954) and, more recently, by Davies & Joyner (1955).

In the older system of intensivism where perches and dropping boards are provided the litter is left in the house for the duration of the egg-laying period. The droppings are removed from the boards at short intervals. By this method a considerable bulk of the faeces is removed from contact with the fowls and is cleared away before the parasite stages within it become infective. Much faecal

matter, however, remains in the litter and if the fowls are parasitized there will be a gradual build-up in the parasite-population. On the other hand, in cases in which the litter is removed regularly and within the times required for the development of oocysts and ova to the infective stages, the chickens will remain susceptible to any coccidial infection they may subsequently encounter. Theoretically, the litter should be changed at least once during every two days to avoid reinfection of birds by pathogenic species of coccidia. Without complete disinfestation, and it is highly probable that this will not be accomplished without the use of coccidiocidal disinfectants, there will be a carry over of infection and, possibly, a gradually increasing population of coccidia, depending on the efficiency with which the cleaning process has been carried out.

Laying Cages and Tier Brooders

Laying cages do not constitute a serious risk with regard to parasitism although parasitic diseases are occasionally recorded. The isolation of individual birds enables the poultryman to detect a sick bird quite readily and appropriate measures can be taken with the minimum of delay. Wire floors, coupled with modern methods of hygiene, do not favour reinfection.

Baby chicks in tier brooders are usually removed from massive reinfection as they are run on wire floors and parasitic diseases occur only rarely. Their almost complete isolation from infective parasites renders them highly susceptible to coccidiosis and disease frequently breaks out when they are transferred to another form of management involving solid floors, or infected ground.

To summarize; the whole question of the relation of poultry husbandry to parasitism revolves round the degree to which susceptible chickens may become exposed to accumulated populations of infective parasites. It is the exposure to large infestations that matters and if these can be reduced the chickens will develop a resistance to them. Large infestations occur where birds are closely confined on ground and litter that is not changed and although there is evidence that birds become resistant under these circumstances, the risk of disease cannot be denied. Excessive crowding of birds favours the increase of parasitism. Wire-floor rearing tends to prevent reinfection but the birds may become highly susceptible to parasitism and such parasitism may attain clinical proportions when the birds are moved from wire floors on to pasture or litter.

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Euthanasia

BY

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THE APPRECIATION OF PAIN BY ANIMALS

The higher vertebrate animals occupy a unique position because, although such animals are thought to have an appreciation of pain comparable with our own, they have no knowledge of our language and so cannot describe painful sensations. When man kills man, the victim or his friends can make his feelings known; when man kills a fly, the process is so quick and the central nervous system of the subject so simple that painful sensations must be negligible. But when man kills one of the higher vertebrates, the operation needs skill and is potentially painful; it is the responsibility of the operator to ensure that unnecessary pain is avoided.

Methods of Assessing Sensation of Pain

Assessment of pain in animals always involves some element of subjective human judgment and hence it will always be a controversial topic. It is impossible to be certain whether or not an animal is feeling pain; it is possible only to make deductions from its behaviour, from a comparison with human sensations, and from physiological observations. The study of animal behaviour is now a science in its own right and the subject is a complicated one. Nevertheless anyone who has close contact with animals learns to recognize signs of fear and pain, and these observations are reliable if interpreted with common-sense. It is far more difficult to be sure that absence of the characteristic signs of fear and pain indicates absence of suffering. If an animal neither cries nor makes any attempt to escape, it is very easy to assume that it is not in pain; it may be paralysed but fully conscious. Drugs, electricity or simply fear may produce paralysis of the voluntary muscles so that an animal cannot move or cry; the sensory side of the nervous system is not then affected and perception may be as acute as in the normal animal. Euthanasia in large animals is often preceded by stunning; when electricity is used for this purpose, it is easy to cause paralysis without unconsciousness if proper precautions are not taken.

A second method of assessment of pain, that of comparison with human feelings, is the most debatable of all methods. Many people do it almost automatically and will argue fiercely about the humanity of some method of killing without considering any other evidence. The validity of such arguments can never be established objectively. No one will deny that the higher animals share some sensations with human beings, but most people will agree that they do not experience all our hopes and fears. This method of assessing pain can give nothing more than circumstantial evidence as to the humanity or otherwise of any particular method of killing.

Finally, physiological experiments can provide objective data about painful sensations, but since these experiments require sensitive instruments and skilled operators, their use in the field is limited. It is possible to carry out experiments on animals in the laboratory and to deduce general rules from these experiments, and some useful work has been done in this way. Observations can be made on the electrical activity of the central nervous system, and on the heart rate. Electro-encephalographs from the brain show whether an animal is conscious or not, and

are one of the few methods available for detecting consciousness in a paralysed animal. It is well known that the heart-rate quickens with sudden pain, and hence continuous electrocardiograms may indicate when a painful stimulus has been received. Results from these laboratory experiments have formed the basis for devising humane methods of slaughter in several instances (Croft, 1952; Roberts, 1954).

Since assessment of pain is such a complex procedure, it is natural that the interpretation of euthanasia—derived from the Greek *eu* (well), *thanatos* (death), and generally defined as "death without any *ante-mortem* associations of fear or pain" — should vary enormously from age to age and from nation to nation. Methods of slaughter depend in the first place on the tools available. The knife and the pole-axe were once considered suitable for any animal; then a knowledge of explosives made possible the introduction of the humane killer, and in more recent times, electricity has been used for both stunning and killing. On the chemical side arsenic and strychnine have been superseded by the barbiturates, though many vertebrate pests are still killed by chemicals which would not be considered humane for the destruction of dogs and cats.

METHODS OF PRODUCING EUTHANASIA

Factors Determining Choice of Method

The circumstances in which an animal is to be killed may determine the method. Techniques such as intravenous injection can only be used if restraint is adequate; in an emergency, such as the escape of a dangerous or rabid animal, shooting may be the only feasible method. When large numbers of animals are being killed, the cost of different procedures must be considered. This economic factor assumes great importance in small-animal work where the drugs used in private practice may well be too expensive for use in a free clinic or dogs' home. Moreover, clinics may often have to rely on unqualified assistants to perform euthanasia; this means that intravenous injection is not a practical procedure and also that drugs included in the Dangerous Drugs Act cannot be used without supervision.

Assuming that circumstances and equipment allow some choice of method, the purpose for which the animal is to be killed must be considered. In countries where meat is part of the normal diet, the majority of the large animals slaughtered will be for human consumption. The species used for food vary in different countries; horsemeat for example is eaten only by a small section of the community in Great Britain, whilst in India the cow is considered sacred and not used for meat, and among orthodox Jews the pig is classed as unfit for human food.

Large animals are also commonly slaughtered either because they are old or sick, or, as in foot and mouth disease epidemics in Britain, because they may spread disease. Euthanasia for these animals is in some ways a simpler problem than for those intended for human consumption, since the condition of the carcass after death need not be considered. More individual care is possible since the numbers to be dealt with at one time are smaller and more time is available. On the other hand carcasses of animals suffering from infectious diseases may need special treatment to ensure destruction of the causal organism after death of the host. Few small animals come into the category of meat-producers, but rabbits and fowls are killed for meat and the state of the carcass after death must be considered in their case just as it is in the larger meat-producing animals.

The subjects used in research laboratories are predominantly small animals, but a certain number of large animals are used for the study of diseases peculiar to those species. The animals used for the production of sera and vaccines and

for medical tests can conveniently be included in this category and involve almost all species from the horse to the mouse. Methods of euthanasia for laboratory animals are frequently determined by the *post-mortem* investigations which are contemplated and no definite rules can be given. Restraint usually presents no problems and the operator is likely to be adept in the technique of intravenous injection. For animals used for the production of sera or vaccines, euthanasia requirements are similar to those for animals required for meat in that in both cases the maximum amount of blood must be drained from the carcass.

Finally some animals are slaughtered under emergency conditions, where the first consideration is the safety of the human being. Animals escape from zoological gardens or parks, or from markets, and through fear or natural ferocity become a danger to the public. Shooting is nearly always the method of choice on such occasions, and when skilfully performed usually provides a quick painless death.

When all these factors have been taken into account, the choice of method may finally depend on the religious convictions or racial traditions of the human being. These convictions and traditions are very strong, and where they conflict with our own ideas on euthanasia, it is not possible to alter them quickly. However, with time and patience and tact, public opinion can be influenced and in the course of generations, methods can be improved.

Of Animals Slaughtered for Meat Production

The process of euthanasia for meat animals can be divided into two stages, preparation and actual slaughter. Certain rules must be observed in both stages if the finished product is to be pleasant in appearance and wholesome. Animals should not be killed when they are fatigued, and they should have an adequate water supply during the hours before slaughter.

Management Before Slaughter

It is said that starvation for up to 24 hours before killing prevents the subsequent penetration of bacteria into the muscles *via* the lymphatics. Pigs are an exception to this rule because their food reserve is not large and starvation mobilizes the glycogen of the liver, so that this organ may not be fit to eat.

If animals are to be rested before slaughter, lairage must be provided on the abattoir premises. This accommodation is often unsuitable, both with regard to cleanliness and to protection from the weather; moreover the animals are sometimes very close to the killing pen, and the smell and sound of slaughter do not help to rest them.

The handling of animals from the time they are unloaded to the time they are killed can cause a great deal of unnecessary suffering, and if bruising occurs through beating or through a fall, the keeping quality of the meat will be impaired. Electric goads help to prevent unlimited use of sticks.

Humane Methods of Slaughter

Assuming that the animal is to be rendered unconscious before slaughter, there are two methods available. The brain can be damaged mechanically or electrically. Until the early 1920's the pole-axe was generally used in Britain for mechanical stunning and it is still used in France for cattle. Similar methods are used in Australia and the U.S.A. where cattle are stunned with a sledge-hammer. A pole-axe can produce instant unconsciousness, but it demands considerable skill and physical strength on the part of the operator, and the animal must be forcibly restrained so that its head cannot move. Cruelty was often manifest in the positioning of the animal and faulty aim resulted in the animal being injured rather than stunned.

Humane Killers

Introduction of humane killers produced a great improvement in slaughter-house technique. These instruments are either of the captive bolt or free bullet type. The former contain a bolt which is expelled a limited distance by an explosive charge and which then recoils to its original position; the free bullet type fires bullets which are of different calibres according to the type of animal to be killed. Both types damage the cerebrum so that consciousness is lost; the other parts of the brain may not be affected, particularly when the captive bolt type is used. If the medulla is not damaged the heart will probably continue to beat, and the respiration may recommence after a brief pause due to shock. The animal is therefore not normally killed by a humane killer but only stunned. The captive bolt model is generally used in abattoirs because there is then no danger of a free bullet injuring human beings. Otherwise incorrect aim or inadequate restraint may result in a free bullet passing out of the animal and ricochetting round the abattoir. On the other hand since the movement of a captive bolt is limited, it is possible that it will not penetrate far enough to cause unconsciousness in a large beast, particularly if the point of contact or the angle is not correct.

The method of use is similar for all types of humane killer. The instrument is loaded and held in contact with the animal's head; as soon as the operator is satisfied that the aim is correct, and the animal is still, he fires. If all is well, the animal drops instantly. The instrument is usually aimed from in front at a point near intersection of the diagonals connecting eyes and bases of ears, or bases of horns. The exact central point is avoided since there is a bony ridge running down the mid-line. Sheep or goats with massive horns are sometimes shot from behind, the point for contact being immediately behind the occipital protuberance, the bolt or bullet being aimed at the mouth of the animal. This aim is not so simple as the anterior one, since a slight error will cause the missile to strike the thick occipital shelf and the brain will not be damaged. Humane killers, like all fire-arms, must be treated with respect and never aimed indiscriminately; they must also be kept clean and free from rust. They have been designed so that a minimum of maintenance is necessary and mechanical troubles are rare. Occasional accidents are reported, but nevertheless the introduction of the humane killer marked a tremendous advance in the history of euthanasia for large animals.

Electric Stunning

Electrical stunning is used extensively in England for pigs and to a lesser extent for sheep and calves; in Holland it is also used for cattle and in South Africa for cattle and horses. An electric current is passed through the brain from electrodes on each side of the head and instant unconsciousness results, but the animal is still alive. This is one of the occasions when human experience can be used as a guide to the feelings of the animal. Electro-convulsant therapy in man is based on a similar technique and patients affirm that unconsciousness occurs without any painful prelude so long as the electrical conditions are correct.

It is essential to use alternating current and to produce an adequate current density in the right part of the brain. The mains supply in most parts of the world is alternating current and the frequency is suitable. The current density in the cerebrum is in practice largely determined by two factors, the voltage applied and the resistance at the junction between the electrodes and the animal's skin. In England the mains voltage is transformed down to about a third of its normal value, so that any danger to the operators is minimized and so that the animal is not killed. The mains voltage fluctuates considerably with the load on it in most parts of the country, and these variations may at times make the voltage in the stunning apparatus dangerously low. The resistance may on the other hand become dangerously large if the slaughterman is tired and does not press the

tongs firmly against the pig's head, or if the animal has a thick coat of hair or mud, or if the electrodes have become worn so that the pad surface is no longer convex. The standard models used in Britain give no indication of the value of voltage or current, or even of whether current is flowing at all. The only indication in the past has been the behaviour of the animal. Insufficient current causes pain in man, and the behaviour of the animal indicates that it does so in animals too.

The other danger associated with electrical stunning is that of electrical "curarization". The animal may appear to be unconscious. This condition of electrical "curarization" was first observed in human beings during accidental electrocution, and it has recently been shown to occur in animals. When an animal is successfully stunned, there is first a period when it is completely unconscious, and this is followed by a period of "curarization" after which normal consciousness with its associated control of voluntary muscle returns. There is a risk that if killing is delayed, the animal may be "curarized" rather than unconscious when it is actually slaughtered. The time relations for these various stages have been worked out by experimental physiologists, and the typical appearance of an electrically stunned animal has been described. Hence it is now possible for slaughtermen to know whether their apparatus is working effectively, and for managers of abattoirs and bacon factories to ensure that animals are killed while unconscious, rather than while they are "curarized" (Croft, 1952).

In America humanitarians have made several attempts to introduce electrical stunning for pigs, but the authorities have always raised strong objections. They say that it increases the incidence of haemorrhages in the carcass, so that "splash" occurs, and that it is difficult to distinguish between this splash and the haemorrhages due to swine fever.

Bleeding

The actual method of killing meat animals is basically the same in most countries, since the primary object is to drain as much blood as possible from the carcass. This improves the keeping quality and appearance of the meat, and in the case of Jews, assists them to keep the law which forbids eating of blood. The great vessels in the neck are severed with a sharp instrument and since the heart is still beating, much of the blood in the body drains out from those vessels. In kosher killing this throat-cut is performed by a rabbi and great care is taken in the preparation of the knife. This part of the Jewish killing is in fact performed with skill and care; the humanity of the preparation of the animal is debatable, but the technique of the throat-cut cannot be criticized.

Much argument has centred round the effect of the throat-cut on consciousness. Some laboratory experiments have indicated that consciousness is lost in 2–3 seconds after the complete severance of the arteries concerned; on the other hand it has been established that stopping the circulation in cats, dogs and man does not cause loss of consciousness until after an interval of 12–15 seconds. The cerebral cells can apparently obtain sufficient oxygen for normal metabolism during this period without any fresh supply of blood. The discrepancy may be due to the fact that in one case the blood vessels are emptied while in the other they contain stagnating blood. The vertebral arteries which form part of the cerebral blood supply are not severed in the Jewish ritual throat-cut, being contained within the bodies of the cervical vertebrae so it is unlikely that rapid cerebral anaemia occurs. Protagonists of the Jewish method say that the animal bleeds out more completely if it is not stunned before death. Other authorities contend that the white colour of kosher meat is due to violent respiratory efforts at the time of the throat-cut, which result in an increased proportion of oxy-haemoglobin in the blood. Thus the blood which does remain in the carcass will be lighter than normal in colour and the meat will appear to be very well bled.

When electrical stunning was first introduced in Britain, butchers said that it increased the incidence of "splash". The matter was carefully investigated by a number of experts and it was decided that there was no evidence to support this statement. If very high voltage is used, or if there is undue delay between stunning and bleeding, splash may follow electrical stunning; but if the procedure is applied correctly there is no damage whatever to the carcass meat (Anthony, 1951).

Ritual Slaughter

The final phase of preparation involves restraint of the animal so that it can be safely killed by the chosen method. Wide differences of opinion arise here, associated with religious beliefs.

Jews and Mohammedans have always held that an animal must be conscious when it is killed, and hence they cannot stun it to prevent movement prior to the throat-cut. In the past this led to considerable rough-handling of beasts in order to cast them and expose the ventral surface of the neck. The comparatively recent introduction of the Weinberg pen has obviated much of the cruelty associated with casting, and now, on the Continent, electrical stunning is considered compatible with the production of "Kosher" meat. In fact in Switzerland and the Scandinavian countries mechanical stunning is now compulsory in the slaughter of animals for Jewish consumption. These modifications to the old ritual killing are not yet practised in all abattoirs and electrical stunning is not yet approved for Kosher killing in Britain.

Mohammedan slaughtermen also normally kill without previous stunning, but their principal objection to stunning appears to be the possibility that the instruments might previously have become contaminated by being used for the slaughter of pigs. However, so long as the instruments have never been used on pigs, the Mohammedan ritual does allow stunning before killing. The essential feature of the slaughter is the utterance of certain prayers before the animal actually dies; whether or not it is conscious when these prayers are said is apparently of no great importance.

In India all animals are killed without stunning and a variation on the throat-cut may be seen in the Sikh method. This involves complete decapitation of the animal by a single stroke of the sword. This act obviously requires great skill on the part of the slaughter-man; humanitarian considerations are similar to those associated with kosher killing, except that in this case the vertebral arteries are cut and the spinal cord is also severed at the moment of killing.

Severance of Spinal Cord

The spinal cord is also cut in the method used in Italy and South America when a short double-edged puntilla is plunged into the atlanto-occipital space. A modification of this procedure may be seen in North Norway, where a curved knife is plunged in to cut the cord and then turned forward to destroy the brain. Penetration of the atlanto-occipital space is not difficult in most species provided that the animal's head can be strongly flexed ventrally, and there seems every reason to assume that unconsciousness occurs immediately the cord is completely severed. The common method of killing rabbits and birds in Britain by jerking back the head has the same physiological basis.

Carbon Dioxide Anaesthesia

A method of stunning by inhalation of carbon dioxide has recently been introduced. The pigs are passed through a tunnel containing gas, and this seems a satisfactory procedure from both the physiological and practical standpoints.

General Comments

The actual process of killing meat animals is humane in most of the methods described and does not conflict with the definition of euthanasia which specifies that death shall be 'quick and easy'. The preparation of the beast for slaughter is much less satisfactory from the humane point of view; euthanasia demands that the animal shall die 'without any *ante-mortem* associations of pain or fear', and few abattoirs can claim to fulfil this part of the definition.

In Disease and Accident

The factors affecting euthanasia for sick or old animals are quite different from those involved in meat production. There is no need to drain blood from the carcass, and more individual attention can usually be given to each animal; thus, intravenous injection is feasible and more expensive drugs can be used. The majority of animals in this category are small animals, but some horses and farm animals do also come into it.

The methods of killing these larger animals are essentially the same as for meat animals, except that the whole brain is destroyed after stunning and no throat-cut is made. If a free bullet type of humane killer is used, the whole brain can usually be destroyed by the shot, but if a captive bolt model is used a rod or stick is necessary to destroy the medulla after the bolt has produced unconsciousness by damaging the cerebrum.

There are many possible methods of euthanasia for dogs; the best technique for any particular occasion can be decided only by considering the ability of the operator, the assistance available, the type and temperament of the dog, and the drugs and equipment available.

Dogs can be shot with a shot-gun or humane killer, and when the owner has the necessary skill and nerve to shoot his own dog, this provides one of the best examples of euthanasia. Shooting does involve considerable bloodshed, and this is a disadvantage in enclosed surroundings and in hot weather.

Electrocution

Electrocution has been extensively used by clinics and dogs' homes for the past 20 years, largely because it is cheap and apparently simple. The current is passed through the dog's heart from a chain collar electrode to a shackle electrode on the hind leg or to a metal floor electrode. The current does not pass through the brain. The dog is killed by the action of the current on the heart; when a sufficiently large current has passed for a long enough period of time, the heart is thrown into fibrillation and blood no longer circulates. This process is irreversible in the dog; in the cat the heart may start to beat normally again when the current is stopped, even if it has been in fibrillation. Hence cats must be watched carefully after removal from the cabinet, or preferably given a lethal injection before the heart begins to beat again. Current was usually passed for 30 seconds when a dog was electrocuted and for 60 seconds when a cat was being killed.

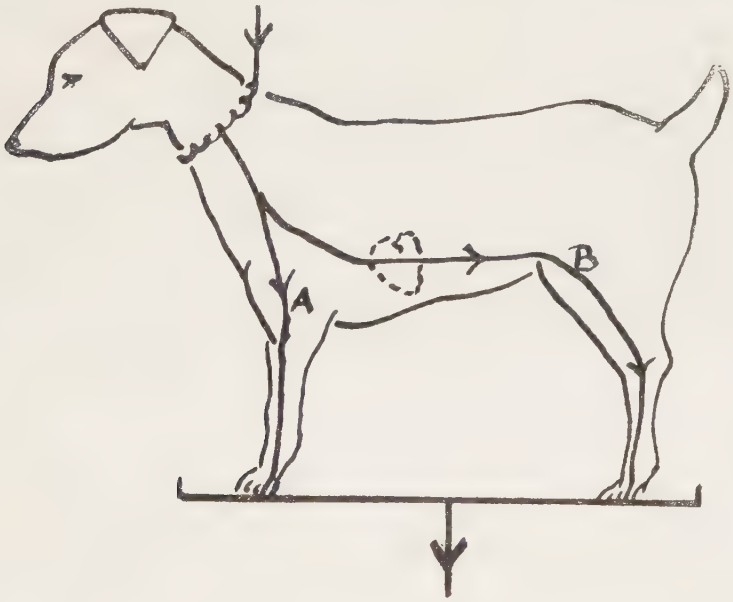
The effect of electricity on the heart depends on the strength of the current and the time for which it flows. The strength of the current in turn depends on the applied voltage and the resistance of the animal at the point of application of the electrodes and in its tissues. The applied voltage in electrocution cabinets was normally 500 or 1,000 volts, the mains voltage of 200-250 volts being stepped up by a transformer to produce this value. The standard cabinet had no voltmeter, and if the mains voltage fluctuated or if the transformer was defective, the only indication that the voltage was too low was the behaviour of the dog which was not killed outright.

The other factor affecting the current, the resistance, varies with the individual animal; the greater part of this resistance occurs at the elecrode/skin junctions, where the chain collar lies on the dog's neck, and where the dog's feet or hind leg

touch the second electrode. Hair and grease are bad conductors, and so dogs with thick coats are more difficult to electrocute than those with sleek coats.

The path taken by the current through the body is not known with certainty, but since body fluids are good conductors, it is logical to assume that the current will flow by the shortest route from one electrode to the other. When the electrodes are a collar chain and a hind-leg shackle the greater proportion of the current will presumably influence the heart. When, however, the hind-leg shackle is replaced by a metal tray for the feet the current will take two paths, A and B (Fig. 1). The electricity in path A will not affect the heart, and the proportion passing along this route has never been determined.

FIGURE 1



Paths of electric current in old electrocution cabinet

Until recently it had been assumed that as soon as the heart started to fibrillate, the animal was dead. In 1934 and 1938 papers by Simpson & Darbyshire and Sugar & Gerard showed that this was not necessarily true. Experiments in which the circulation to the brain was stopped while continuous electro-encephalograph recordings (EEG) were taken, showed that the electrical activity of the cerebral cells was normal for 12–15 seconds after the circulation was stopped. There were individual variations and some parts of the brain were more sensitive to anoxia than others, but there was every indication that consciousness was normal for at least 12 seconds. Personal observations from a human subject supported this view. If these experimental results were confirmed, it was obvious that the existing method of electrocution could not be classed as euthanasia. Even if the current was such that the heart was immediately thrown into fibrillation, the dog would still be conscious for 12 seconds, and as current would be passing through its body it would be in pain for that period of time.

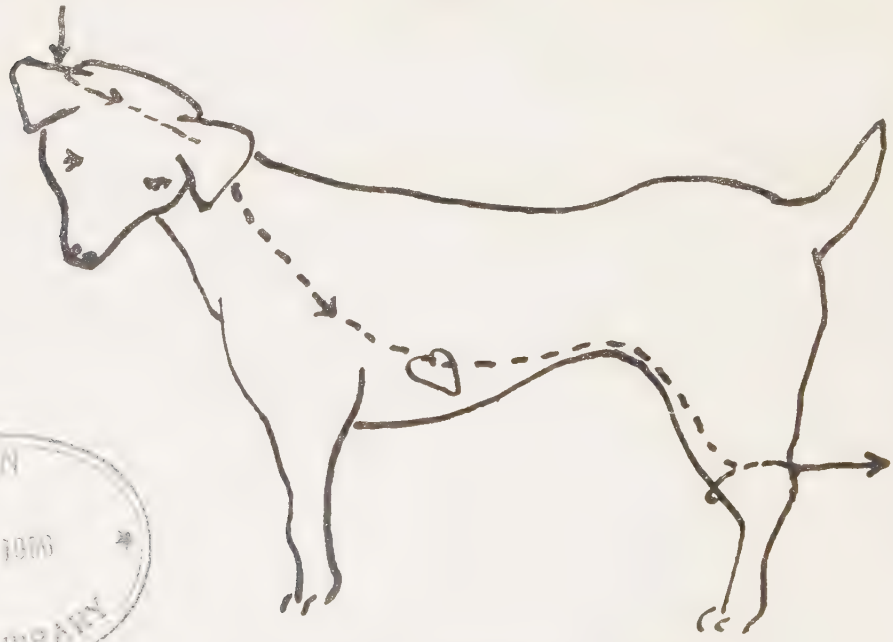
The whole matter was therefore re-investigated in Glasgow using dogs as subjects and studying the state of consciousness during electrocution by EEG (Roberts 1954). These experimental results confirmed the earlier findings and the

existing method of electrocution was thereupon condemned by the British Veterinary Association. It was evident that the current must be used first to stun the dog; after that the dog could be painlessly killed by the effect of the current on the heart as in the old method. Electro-convulsant therapy in man, and electric stunning in bacon factories showed that it is relatively easy to produce unconsciousness painlessly if an electric current can be passed across the brain. The essence of the problem was, therefore, to devise electrodes which would ensure that the brain was in the path of the current.

There were already a number of people who had designed apparatus for this purpose because they were doubtful about the humanity of the old procedure. Dr. Voute in Holland, in collaboration with one of the Dutch universities, had perfected a method in which alternating current at mains voltage was passed from the right ear of the dog or cat to the lower left flank. The current flowed diagonally across the body through both brain and heart, so that the animal was first stunned and then killed. Dr. Voute used artery forceps as electrodes, clipping one pair on to the wetted ear-flap and the other on to a wetted fold of skin on the flank. The equipment was thus portable and could be used in an owner's home wherever there was an electric point. This apparatus has been used successfully in Holland for a number of years for both dogs and cats.

Another apparatus which passes current through brain and heart has been in use for several years at a dogs' home near Carlisle. The head electrode in this equipment consists of a malleable metal plate which lies directly over the brain, and is kept in position by attached leather straps and a collar. Three different sizes of plate have been found adequate to dealt with all breeds of dog. This electrode has the merit that the current is applied immediately over the brain; the ears are usually slightly behind the centre of the cerebrum and electrodes which use the ears must therefore be placed on the anterior border. On the other hand it is more difficult to ensure close contact between electrode and skin when the plate is strapped to the dog's head.

FIGURE 2



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Path of current in new electrocution cabinet

During the past two years an apparatus known as an electrothanator has been developed in Great Britain and tested extensively in North Africa and in Britain by organizations which were not satisfied with the old procedure. The current flows across the brain from one ear to the other and then through the body to the hind leg, so that the dog is stunned initially and subsequently killed. The electrodes for the ears are basically similar to crocodile clips, but in place of the serrated jaws there are stainless steel discs which hold pads of lint; these can be saturated with electrolyte and cause the dog no pain when they are applied. The hind leg electrode is a chain shackle similar to that in the old cabinets. The electrothanator can be incorporated in a cabinet or it can be used as a portable apparatus. It is equipped with meters which indicate when conditions are suitable for electrocution; thus if an electrode is making poor contact with the dog's skin, the meters will show that there is a fault somewhere in the circuit before the full current is switched on. It is no longer necessary to switch on and see what happens to the dog.

Electrocution apparatus for use in clinics must be simple so that a layman can use it without danger to the animal or himself; its use must involve a minimum of handling of the animal and at the same time it must provide adequate restraint. Above all, it must ensure that sufficient electrical energy will be generated in the brain to stun, and in the heart to kill. The British Veterinary Association which has instigated much of the recent work on this subject, has summarized the technical requirements (1954). The electrothanator, which is now available in Great Britain, fulfils these requirements, and seems to be satisfactory for the electrocution of dogs. As yet there is no satisfactory apparatus for the electrocution of cats, but work on this problem is in progress.

Euthanasia for cats has always been a difficult problem. Intravenous injection is not often possible and electrocution has never been satisfactory. Cat fur is a very poor electrical conductor and so electrodes have usually been put in contact with the feet; these are not good conductors at any time and when the claws are extruded the electrical resistance at the electrode/animal junction is much too high. The current does not pass through the brain, so that the same humanitarian objection arises as in the electrocution of dogs.

Drugs

There are many drugs which can be used for small-animal euthanasia and the majority of them can be given orally or by injection.

Dogs

In the past, two methods commonly used for the destruction of dogs were the oral administration of strychnine and the intrathoracic injection of hydrogen cyanide. We now know that neither method constitutes euthanasia and that neither should ever be used for destruction of a conscious animal. These two drugs have no appreciable effect on the higher centres of the brain, and hence the processes leading to death, such as spasm of the respiratory muscles, occur while the dog is conscious. If intravenous injection is feasible, there are two good methods available for euthanasia; a saturated solution of magnesium sulphate can be injected or an anaesthetic dose of a suitable barbiturate such as pentobarbitone can be given. Occasional failures are reported with magnesium sulphate, but these can usually be traced to use of a solution which was not saturated. When correctly

administered, magnesium sulphate is a quick and cheap lethal agent. An anaesthetic dose of barbiturate must be followed by the actual killing of the unconscious dog; this is often done by injection of hydrogen cyanide intrathoracically. Alternatively, a lethal injection can be given in the first place; this is simpler but more expensive.

If intravenous injection is difficult, barbiturates can be given by many other routes; intrathoracic and intraperitoneal injection and oral administration are all satisfactory. The disadvantage of these routes is that absorption is slow and variable, and it may be necessary to wait 10–40 minutes before the animal is unconscious. Morphine or one of its modern synthetic substitutes can be given by intramuscular injection. This involves a similar delay, with the added disadvantage that defaecation and vomiting commonly occur. Theoretically, intracardial injection of barbiturates could be used as a method of euthanasia, but in practice this procedure is unsatisfactory because the dog's heart is small and variable in position. Some workers have advocated injection of a lethal agent into the atlanto-occipital space; this is certainly feasible, but seems to offer no special advantages over the accepted methods.

Cats

Morphine and its synthetic substitutes cause excitement rather than sedation in the cat. Pentobarbitone can be given orally or by intrathoracic or intraperitoneal injection and this is probably the best solution to the problem of feline euthanasia. Cats can be chloroformed and many of them seem to pass into unconsciousness peacefully while inhaling chloroform; some animals, however, pass through a stage of excitement and frenzy. The best method of chloroforming cats is by using a box similar to that supplied by the R.S.P.C.A. The relative concentrations of air and chloroform can be regulated easily in these boxes and hence the chloroform can be introduced gradually. Cats should never be plunged suddenly into a heavy concentration of chloroform vapour and the liquid should never be allowed to touch the animal's face since it is irritant. Dogs cannot be chloroformed satisfactorily because the phase of excitement is marked.

Birds

The principle of a chloroform box can be used for destruction of smaller mammals, and birds other than diving birds. A bell-jar or a desiccator may be used instead of a box, so long as a variable air supply is arranged. If chloroform is not available, coal-gas may be used so long as the percentage of carbon monoxide in it is adequate.

Euthanasia of Unwanted New-Born Animals

Unwanted new-born animals may conveniently be included in this category of disease and accident. Many veterinary surgeons will confirm that the vitality of new-born animals is sometimes remarkable. The methods suitable for adult animals can almost always be used for the young of the species, but there are some additional procedures available. Kids, for instance, can be killed satisfactorily by intracardial injection of pentobarbitone, since the heart is relatively large and the amount of the drug needed is not excessive. Puppies and kittens can be chloroformed or destroyed by the intraperitoneal injection of pentobarbitone; the common practice of drowning these animals cannot be considered as euthanasia, since it is slow and appears to arouse fear while the

animal is still conscious. Destruction of day-old chicks in hatcheries is a problem which has not yet been satisfactorily solved. Some form of gassing will probably prove to be the best solution.

Special Considerations in Disease

Certain pathological conditions require special methods of euthanasia. Animals affected with anthrax for instance must be killed by inhalation of chloroform or by injection in such a way that no blood is shed. Intraperitoneal injections are not satisfactory in animals with dropsy and inhalation methods should not be used if the animal's respiratory system is affected.

Co-operation of the Owner

Few people can doubt that dogs and cats often have strong links with their human owners and the presence of a calm owner can contribute enormously to the peace of mind of the animal during euthanasia. If the owner cannot be with the dog or cat at this stage, the interval between the owner's departure and the animal's loss of consciousness should be as brief as possible. There are few more pathetic sights than dogs tied up at a surgery waiting until someone has time to destroy them.

For Purposes of Research

Euthanasia of laboratory animals includes species ranging from the horse to the mouse, and the reasons for which the animal is being killed often make the usual method of euthanasia unsuitable. Many animals are killed after special treatment such as hyperimmunization in order to extract some product from their blood. The principles governing slaughter for meat production are then applicable; the animal must first be anaesthetized and then, while it is unconscious, the maximum amount of blood must be drained from the body by catheterizing a suitable vessel. Death from cerebral anaemia occurs while the animal is still unconscious.

If some particular organ is to be used for research *post mortem,* the system including that organ must not be affected by the method adopted for euthanasia. Thus if the central nervous system is to be examined the animal must not be shot, or if the lungs are of interest, inhalation anaesthesia cannot be given. Again, if research on fat metabolism is contemplated, ether and chloroform cannot be used because they are fat solvents. When enzyme activity, or the state of blood pigments is of interest, hydrogen cyanide must not be used for killing. Scientists interested in enzyme activity have recently evolved a new method of euthanasia for small laboratory animals. They are plunged into liquid air and instantly frozen solid. They are decapitated while in this condition and *post-mortem* change is reduced to a minimum (Richter & Dawson, 1948). Unless special precautions were taken there would be danger of injury to the operator using this method.

Euthanasia is principally carried out by veterinary surgeons, scientists and slaughtermen. The veterinary surgeon, alone of these three, has as his primary object the well-being of animals. The scientist regards experimental animals as one of the means by which he can gain knowledge and solve problems, whilst the slaughter-man is concerned with the quality of the meat which the animal produces. The veterinary student therefore must be given adequate instruction in the principles of euthanasia and in the methods available, so that he can make an intelligent decision as to the best technique to adopt in any particular set of circumstances. Any theoretical instruction is of little use without opportunities for practice. Injections can be practised on anaesthetized subjects and humane killers can be fired into logs

and into dead animals so that the loading and firing actions become almost automatic.

Euthanasia is often considered in relation to small-animal practice only, but it is surely reasonable that civilized man should slaughter large animals, which have a similar central nervous system to that of a dog or cat, humanely too. A great deal of knowledge is now available concerning techniques and their effects on the animal; it is the veterinary surgeon's duty to be conversant with this knowledge, so that he can render the best possible service to animals and to his clients.

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